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SYSTEM COST PROBABILITY DISTRIBUTIONS for ACES ARCHITECTURES

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May 30, 1989

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) This report derives functional forms and presents the probability distributions for the acquisition and program costs for strategic defense system architectures developed in the second phase of the SDIO sponsored Architecture Comparative Evaluation Study (ACES). The input data are the nominal costs for each of the elements and the cost risk distributions for three elements, one each at low, medium and high risk. These are used as the basis for the cost risk distributions for all the other elements. Both log-normal and normal, independent and correlated distributions are used as the basis for deriving the total cost risk distributions for these alternatives. The results are the probability distributions for the acquisition and program costs for each of five architectures: the DAB Baseline, two all ground based weapon architectures and two all space based architectures. The description of the architectures and the nominal cost models are presented in the ACES report, not in this report. The results show a relatively tight (± 10-15%) distribution about the nominal acquisition and program costs. This is due to our including only technical cost risk and correlations. The larger uncertainity is undoubtedly political: mission, threat and funding. Keywords: Cost Effectiveness. (AU)

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ACES	Architecture Comparative Evaluation Study
BP	Brilliant Pebbles
BSTS	Boost Surveillance and Tracking System
CCSOIF	Command, Control and System Operating and Integrating Functions
DAB	Defense Acquisition Board
ERIS	Exoatmospheric Reentry Vehicle Intercept System
GSTS	Ground-Based Space Surveillance and Tracking System
HEDI	High Endoatmospheric Intercept System
LCH	Launch
MGBR	Midcourse Ground-Based Radar
SBI	Space Based Interceptor
SEI	System Engineering and Integration
SSTS	Space Surveillance and Tracking System
TGBR	Terminal Ground-Based Radar

I INTRODUCTION

The purposes of this paper are to present estimates of the probability distributions for the acquisition and program costs for the alternative architectures discussed in the Architecture Comparative Evaluation Study (ACES) [Ref 1], and to describe the procedures we used to develop them. In our first pass through these evaluations, we will assume that the distributions for the cost of R&D and Investment for an element have equal risk and that all cost distributions are statistically independent. Later, we will relax these assumptions.

PROBLEM DEFINTION

We are seeking a method for determining the probability distributions of two kinds of system costs: acquisition costs and program costs. The acquisition costs are defined as the costs of the R&D and Investment phases on all the defense elements that are deployed with an architecture. The program costs consists of the R&D costs on all the elements that are to be deployed in the initial deployment, the Investment costs for all the elements deployed in the initial deployment, and the R&D costs of the elements to be *deployed in the next phase of deployment.* Thus the program costs include all of the acquisitions costs for an initial deployment plus R&D on near term follow-on elements not included initially.

The architectures are ballistic missile defense systems composed of the following sensor, interceptor and battle management elements:

boost surveillance and tracking system (BSTS),
space surveillance and tracking system (SSTS),
space based interceptor (SBI) or Brilliant Pebbles (BP),
ground-based space surveillance and tracking system (GSTS),
midcourse ground-based radar (MGBR),
exoatmospheric reentry vehicle intercept system (ERIS),
terminal ground-based radar (TGBR),
high endoatmospheric intercept system (HEDI),

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[1] Dyer, JL. et al. "Architecture Comparative Evaluation Study (U)" Volume II, SPARTA Technical Report, McLean, VA <u>SECRET</u> (March 3, 1989)

command, control and system operating and integrating functions (CCSOIF),

system engineering and integration (SEI),

and launch (LCH).

The quantities and qualities of each of these elements, and the cost-quantity estimating relationships are described in the ACES final report.

As we will use the term, the system costs for an architecture includes only the costs for the full scale engineering development (R&D) and deployment (Investment) phase; operations and support (O&S) costs are not included.

INPUT DATA

The inputs to these evaluations of system cost were 1) the nominal costs for each of two phases (R&D and Investment) for each of the elements to be considered in the near term architectures (from ACES) and 2) the cost distributions from the USAF for the combined costs (R&D plus Investment) for three elements: BSTS, SSTS and SBI. We will use the ACES inputs as the nominal costs (either expected values or 50% confidence values), and the USAF data as the source of the cost risk distributions about those nominal values.

In ACES, we have nominal cost estimates for the appropriate quantities of each element in each of its two phases. We do not have cost risk assessments for all of the elements contained in each of these architectures. The three element cost risk estimates that we do have are presented in Figures 1 through 3 for the BSTS, SSTS and SBI respectively. The nominal values in the figures are assumed to have been superseded by the ACES data. However, we can and will use the nature of the underlying distributions for estimating the cost risk. We will determine the characteristics of the distributions from curve fits to the data we take off of these three figures.

We will develop total system costs (total R&D and Investment) from these input data for three different sets of premises: 1) the element costs are log-normally distributed and the nominal (ACES) costs are estimates at the 50% confidence level, 2) the element costs are log-normally distributed and

the nominal costs are expected value estimates, and 3) the costs are normally distributed and the nominal cost are most likely cost estimates.

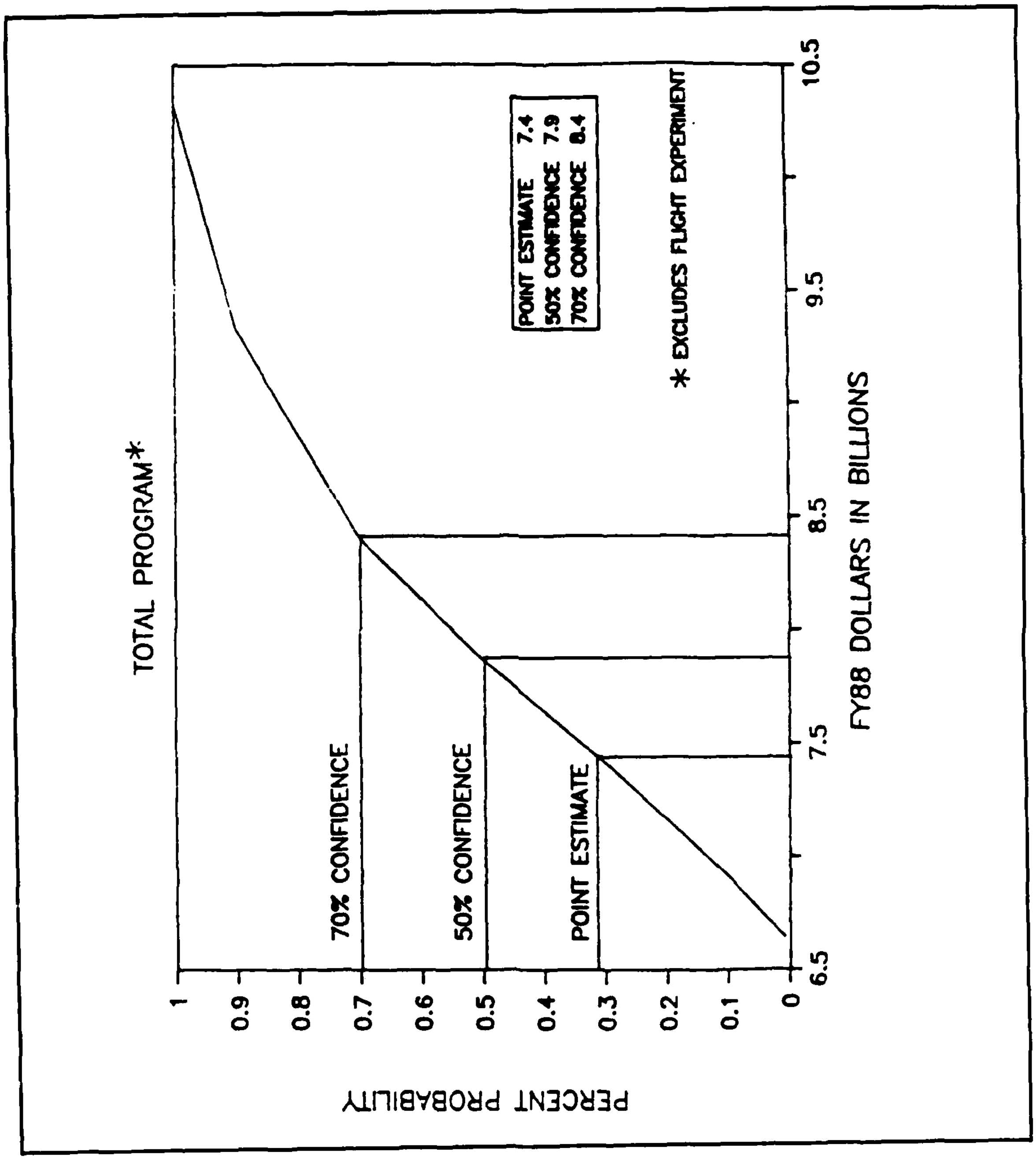

Figure 1. Spring 88 Estimate Updates
BSTS Risk Analysis

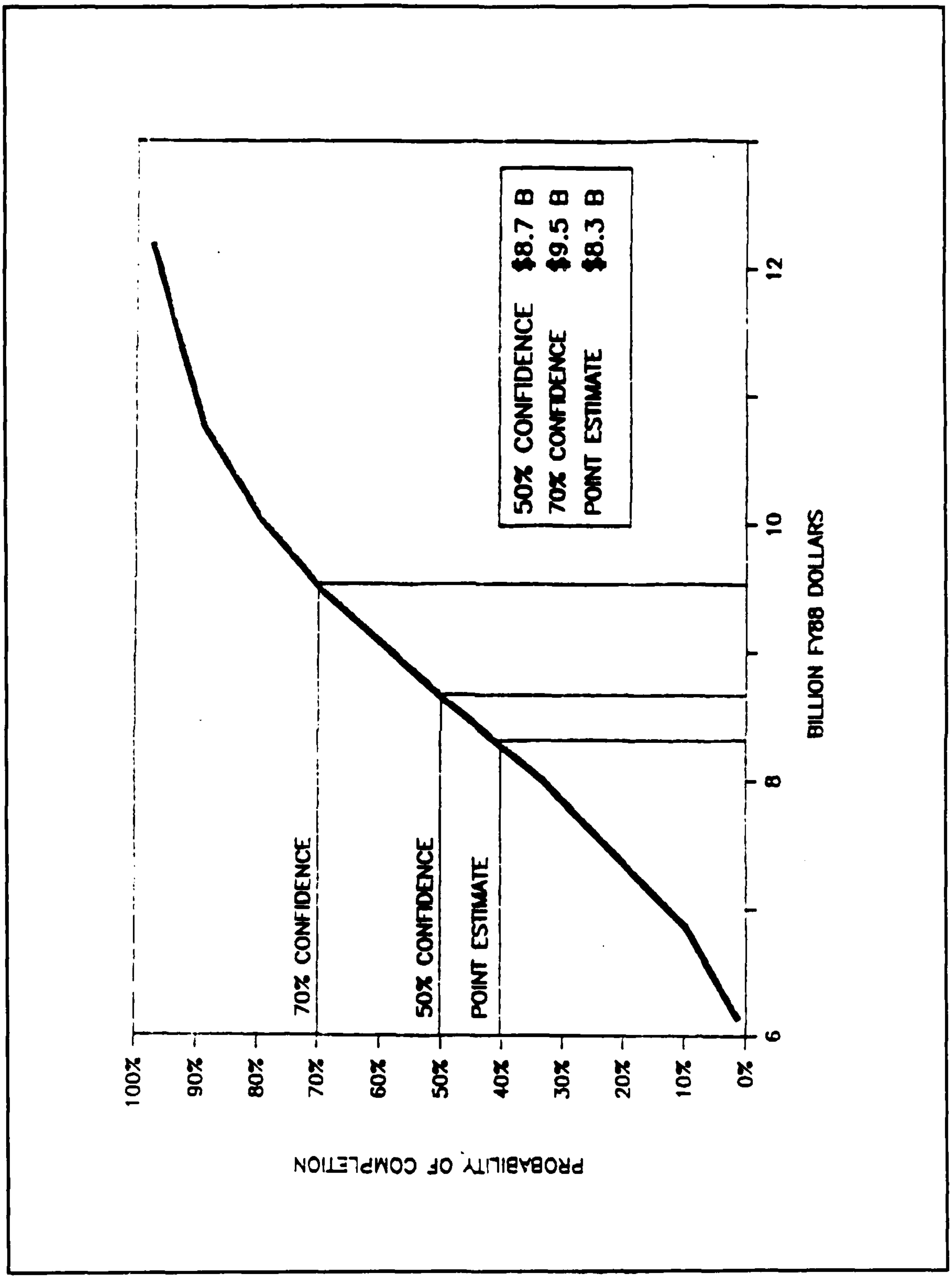

Figure 2. Spring 88 Estimate Updates
SSTS Risk Analysis Results

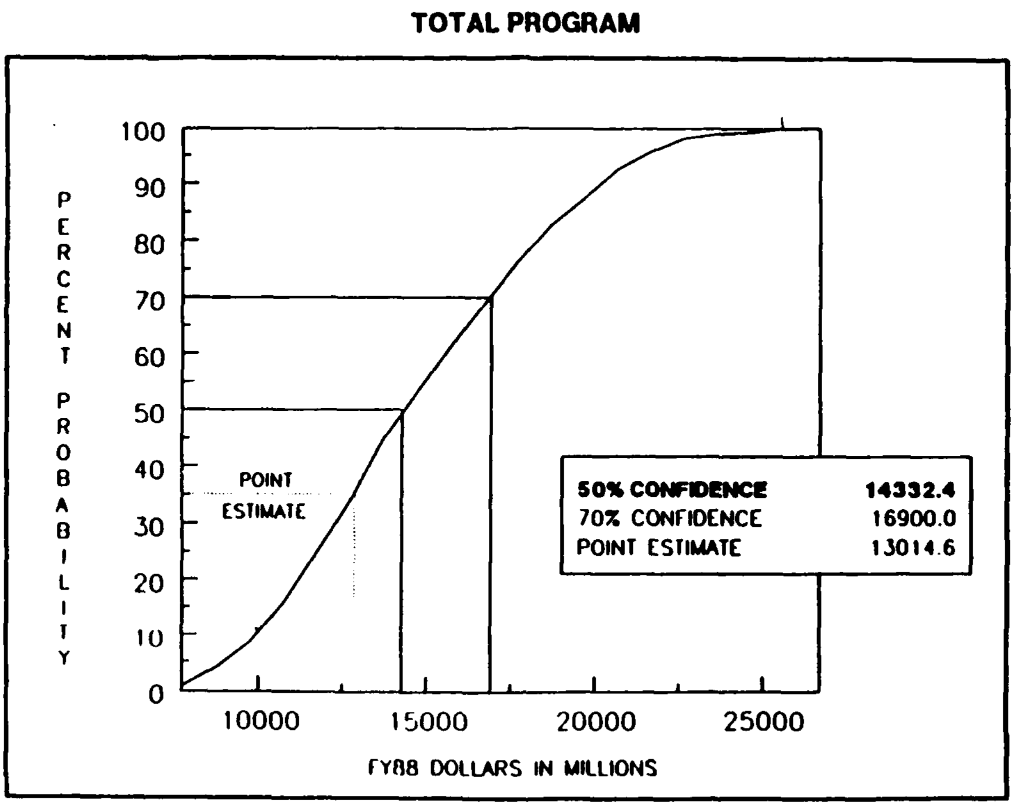

Figure 3. Spring 88 Estimate Updates
SBI Risk Analysis Results

CONTENTS

A summary of the results and our recommended estimates are in the next section. Section II covers the detailed results for the log-normal distribution assumption sets. Section III covers the detailed results for the normal distribution assumption set. In the last section, Section IV, we will examine the sensitivity to our assumptions on risk associated with different program phases and on element independence. A summary of the pertinent features of the log-normal and the normal distribution is presented in Appendix A.

II SUMMARY

In this section, we present three sets of results. In the first subsection, we present the system acquisition and program costs for all five architectures assuming that the cost distributions for each element are independent and that the underlying distributions in each phase for each element are not only independent, but have the same distribution. In the second subsection, we examine a change in the nature of the distribution of risks between R&D and Investment phases. In the third subsection, we present the results for the case where distributions for both phases and elements are correlated. For the costs of the architectures, we recommend using the program costs listed in Table 5. Though these costs are derived without rigorous estimation of the correlation between programs, assuming a complete correlation does model the feature that all elements of an architecture operating at the required performance levels in the necessary quantities are needed to make an architecture meet its mission.

RESULTS FOR INDEPENDENT DISTRIBUTIONS

In Tables 1 through 3, we present the system acquisition and program costs we have developed for each architecture from each of our sets of premises on the nature of the distributions. As we should expect, all three system costs distributions are relatively tight (low variances) and are relatively close in value to one another. The tightness should be expected as a result of the assumption of independence of the distributions of costs for each phase and for each element. The closeness should be expected because the fitted underlying distributions are approximately equal. (We note that the nominal program reserve - an added cost - is not included here.)

Table 1 presents the estimates we made assuming that: 1) the cost distributions for each phase for each element have log-normal distributions, 2) that both the R&D and Investment phases have equivalent cost risk distributions (equal coefficients of variation), and 3) that the input cost data (nominal values) for each phase for each element were equivalent to cost estimates made at the 50% confidence level. The first assumption distinguishes the results of Table 1 from Table 3. The last assumption distinguishes the results of Table 1 from those of Table 2.

Table 2 presents the estimates we made assuming that: 1) the cost distributions for each phase for each element have log-normal distributions, 2) that both the R&D and Investment phases have equivalent cost risk distributions, and 3) that the input cost data (nominal values) for each phase for each element were equivalent to expected value cost estimates.

Table 3 presents the estimates we made assuming that: 1) the cost distributions for each phase for each element have normal distributions, 2) that both the R&D and Investment phases have equivalent cost risk distributions, and 3) that the input cost data for each phase for each element were equivalent to expected value cost estimates (equivalent to 50% confidence estimates for normal distributions).

By the assumption that the input cost data are 50% confidence values the results in Table 1 are biased away from the sum of the nominal costs that is generally cited as the cost of the system. The bias also makes both the lower and upper bounds higher than we see in either Tables 2 or 3. The results of Tables 2 and 3 are essentially equivalent to one another. Except for roundoff differences, the two distributions are everywhere the same.

RESULTS FOR ALTERNATIVE RISK DISTRIBUTIONS

The tightness of the distributions seems to belie the intuitive notion that cost estimates should have large ranges when the systems are only now reaching maturity and are still demanding advances in technology. We considered two alternative assumptions: one on the split of the risk between R&D and Investment and the other on independence. Changing the split in risks did not change the essential nature of the distributions. Following the relative sizes of the TRACE accounts in US Army cost estimates, we assumed that R&D has three times the relative risk as the Investment phase. We modeled this by having the coefficient of variation of the R&D be three times the coefficient of variation for the Investment. For the DAB Architecture, it increased the estimated costs by 1B$.

Table 1
Summary of Acquisition and Program Costs Derived with Independent Log-Normal Distributions Assuming Nominal Inputs are 50% Confidence Values of Cost

Probability	Acquisition Costs				
	Architectures				
	ERIS	ERIS/HEDI	DAB	SBICV	BP
0.20	45	62	66	65	37
0.50	47	64	70	72	39
0.80	49	66	74	79	40

Probability	Program Costs				
	Architectures				
	ERIS	ERIS/HEDI	DAB	SBICV	BP
0.20	55	69	69	75	46
0.50	58	71	73	81	48
0.80	60	74	77	88	50

Table 2
Summary of Acquisition and Program Costs Derived with Independent Log-Normal Distributions Assuming Nominal Inputs are Expected Values of Cost

Probability	Acquisition Costs				
	Architectures				
	ERIS	ERIS/HEDI	DAB	SBICV	BP
0.20	44	61	64	64	36
0.50	46	63	68	70	38
0.80	48	65	72	77	40

Probability	Program Costs				
	Architectures				
	ERIS	ERIS/HEDI	DAB	SBICV	BP
0.20	54	68	67	73	46
0.50	57	70	71	79	47
0.80	59	73	75	86	49

Table 3
Summary of Acquisition and Program Costs Derived with Independent Normal Distributions

Probability	Acquisition Costs				
	Architectures				
	ERIS	ERIS/HEDI	DAB	SBICV	BP
0.20	44	61	64	64	36
0.50	46	63	68	70	38
0.80	48	65	72	77	40

Probability	Program Costs				
	Architectures				
	ERIS	ERIS/HEDI	DAB	SBICV	BP
0.20	54	68	68	73	46
0.50	57	70	72	80	48
0.80	59	73	75	86	50

RESULTS FOR DEPENDENT DISTRIBUTIONS

We considered two kinds of interdependence. The first was a dependence between the costs for the R&D phase and for the Investment phase; the second was a dependence between the costs for the different element programs. Of the two, the latter was the more important. We did not have a basis for estimating the covariance between phases or between elements. In order to proceed, we assumed two values of the correlation coefficient, one for between phases and one for between program elements, and we assumed that these correlation coefficients were everywhere the same. We then examined the system costs as a function of changing values in those two coefficients. Thus, the results can only be considered indicative. Of course, the upper bound on the costs cannot be higher than when we assume all program elements are completely correlated. Assuming underlying normal distributions, Table 4 presents the system cost results for the assumption that the correlation coefficient both between program phases and between program elements was 0.50. As expected, these costs are higher than those presented in Table 3, but only by about 5%.

Table 4
Summary of Acquisition and Program Costs Derived with Normal Distributions and Assuming Program Phases and Elements are Correlated with Coefficient 0.50

Acquisition Costs					
Probability					
	Architectures				
	ERIS	ERIS/HEDI	DAB	SBICV	BP
0.20	42	58	61	61	34
0.50	46	63	68	70	38
0.80	51	68	75	80	42
Program Costs					
Probability					
	Architectures				
	ERIS	ERIS/HEDI	DAB	SBICV	BP
0.20	51	64	64	70	43
0.50	57	70	72	80	48
0.80	62	77	79	90	52

In Table 5, we present the same data for the case where the programs are completely correlated (the coefficient of correlation between phases is still at 0.50). After adding in the program reserve amount, these are the costs we recommend using for estimates of the costs of the ACES Architectures.

The upper bounds (80% Confidence Values) on the system acquisition costs as a function of the assumed correlation coefficient between elements are compared for each of the five architectures in Figure 4. While the correlation coefficient is not known, its distribution of values will undoubtedly lie somewhere between the bounds given. In the bar graph of Figure 5, we present the system acquisition costs so that both upper (80%) and lower (20%) confidence bounds for correlated and uncorrelated cases and the expected value can be seen. The larger and the smaller values for the upper and lower confidence bounds are for the completely correlated case; the smaller and larger values for the upper and lower confidence bounds are for the completely independent case. The same kinds of data are presented in Figures 6 and 7 for the system program costs. The correlated cost uncertainties for the DAB Architecture are approximately 14%.

Table 5
Summary of Acquisition and Program Costs when Program Elements are Completly Correlated

Acquisition Costs					
Probability	Architectures				
	ERIS	ERIS/HEDI	DAB	SBICV	BP
0.20	41	57	59	59	33
0.50	46	63	68	70	38
0.80	52	69	77	82	43

Program Costs					
Probability	Architectures				
	ERIS	ERIS/HEDI	DAB	SBICV	BP
0.20	49	62	62	67	41
0.50	57	70	72	80	48
0.80	64	79	82	92	54

We note in passing that evaluating the completely correlated case with the log-normal distributions instead of with the normal distributions will yield very similar results

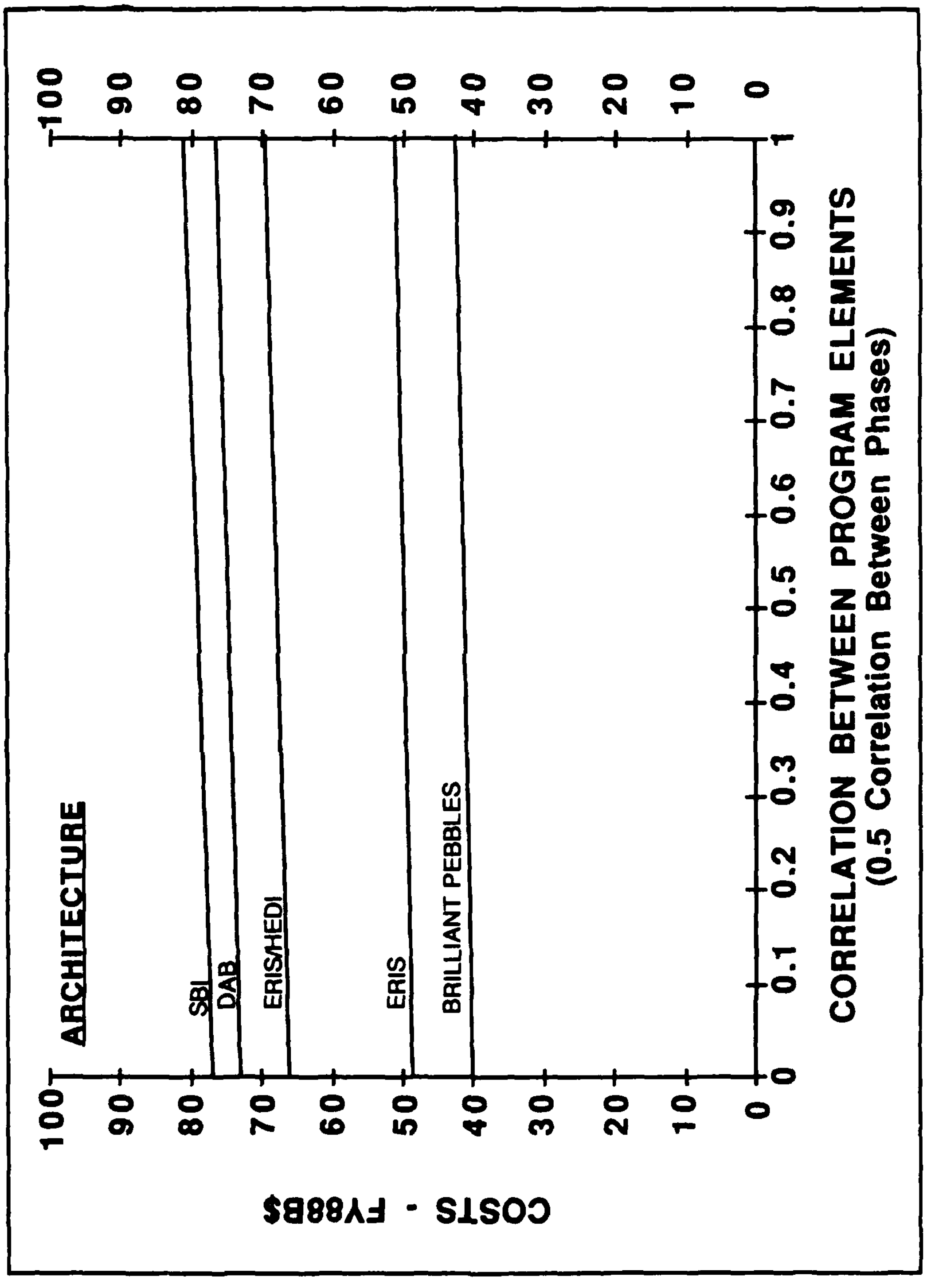

Figure 4. Comparison of Upper Bounds of Acquisition Costs

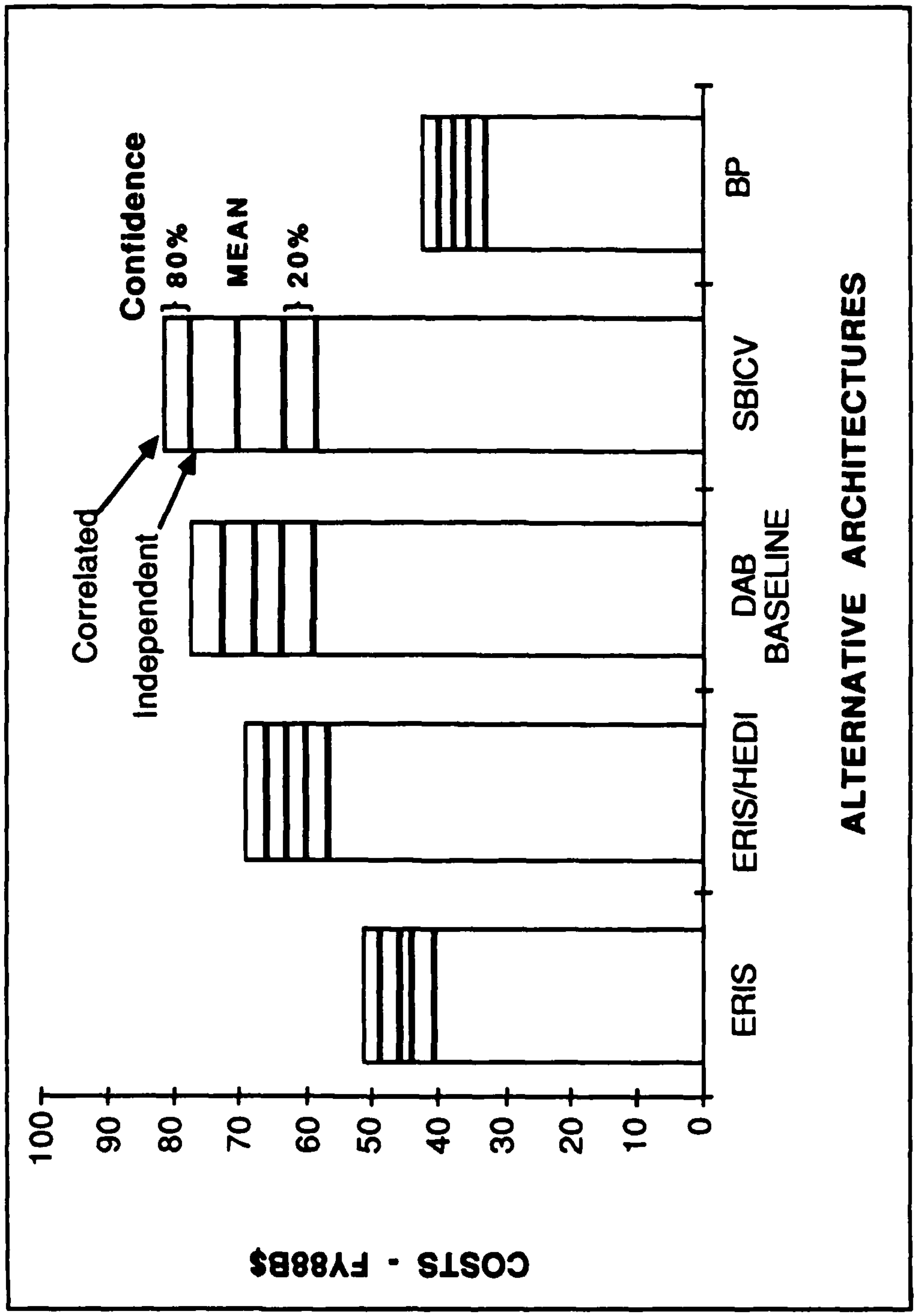

Figure 5. Comparison of Acquisition Cost Ranges

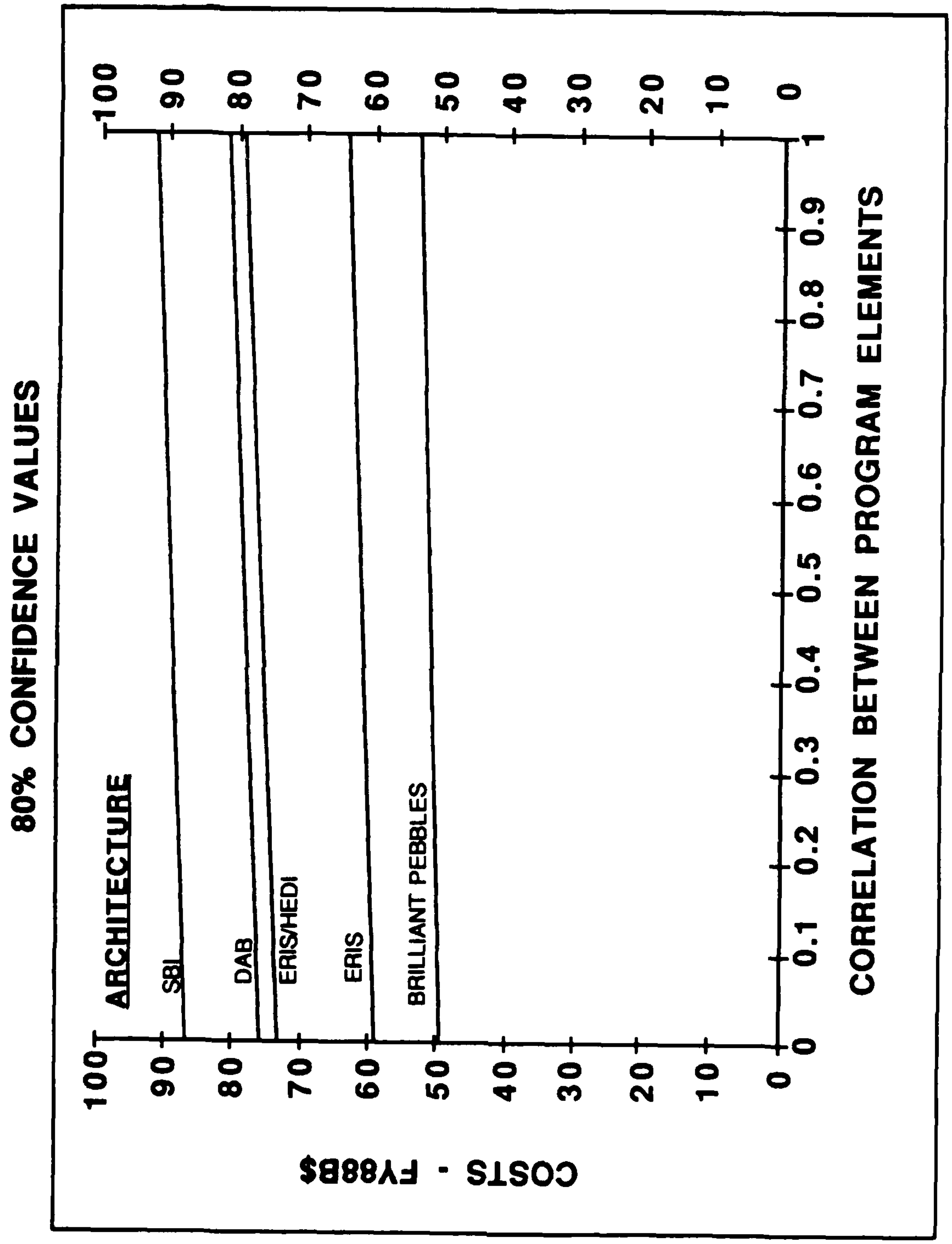

Figure 6. Comparison of Upper Bounds of Program Costs

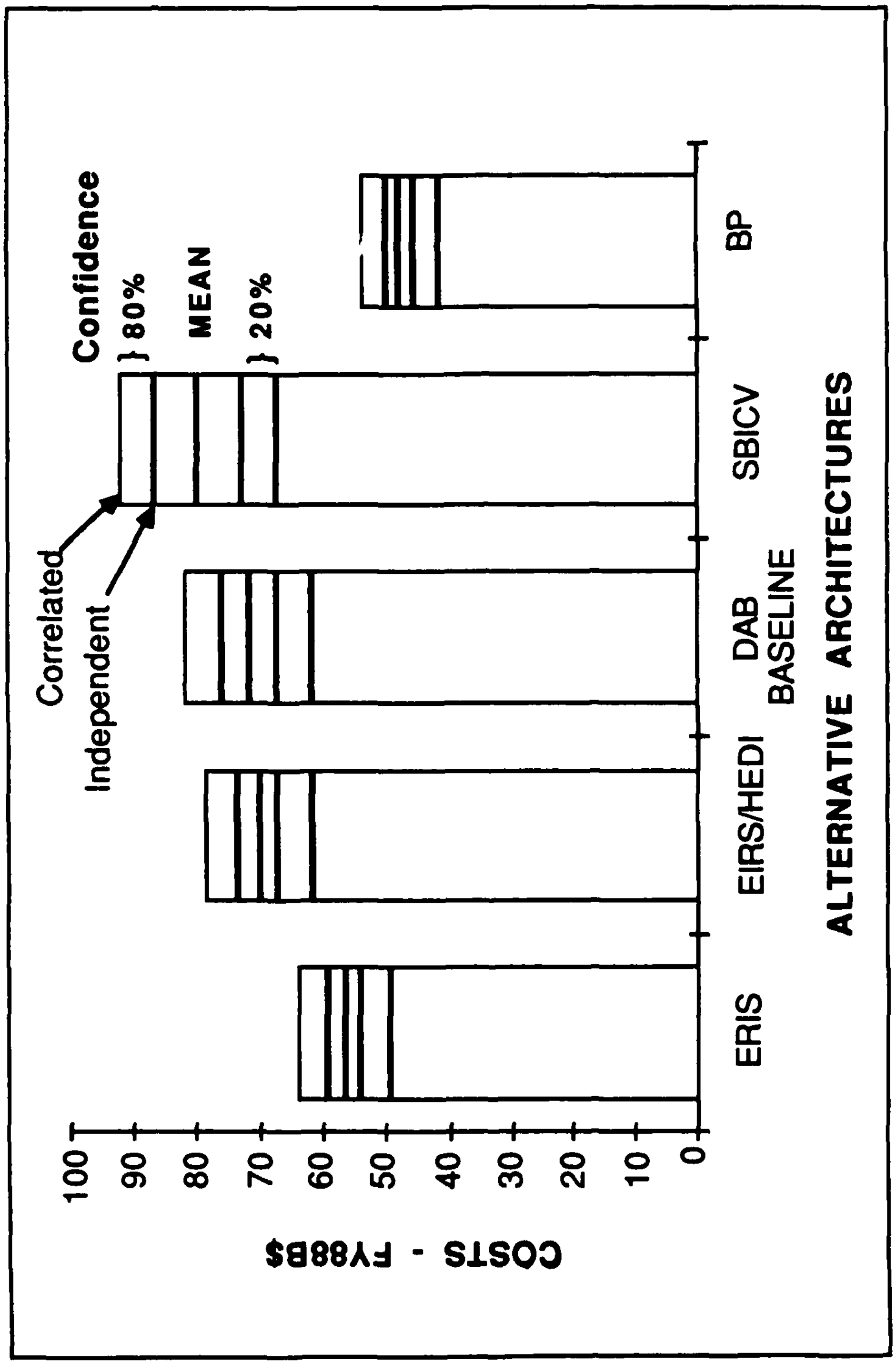

Figure 7. Comparison of Program Cost Ranges

III APPROACH USING LOG-NORMAL DISTRIBUTIONS

The assumptions implicit in our approach in this section of the report are the following:

The costs (random variables) for each phase (R&D and Investment) for each element in an architecture are independent.

The probability function for the cost of a phase for an element has a log-normal distribution.

The nature of the cost distribution is constant by phase, that is, the cost risk distribution (probability of a cost) for an element in R&D is similar to the risk distribution for deployment (investment). We will represent this assumption by saying that the coefficient of variation remains constant.

The elements are divided into three categories: those with high risk, those with moderate risk, and those with low risk. Within a constant risk category, the coefficient of variation is the same.

Important relationships for the log-normal density function are given in Table 6.

Table 6.
Log-Normal Distribution Definitions

Density Function

$$f_X(x) = \exp[-1/2\,(\ln x - \mu)^2/\sigma^2] \,/\, [\sqrt{(2\pi)}\,\sigma x] \qquad o < x < \infty,\quad \mu > o,\quad \sigma > o$$

Cumulative Distribution Function

$$F_X(x) = \Phi[(\ln x - \mu) / \sigma]$$

Fifty Percent Confidence Value

$$X_{50} = \exp(\mu)$$

Expected Value

$$E(X) = \exp[\mu + (1/2)\sigma^2]$$

Variance

$$VAR(X) = \{\exp[2\sigma^2] - \exp[\sigma^2]\}\ \exp[2\mu]$$

Mode

$$x^* = \exp(\mu - \sigma^2)$$

Coefficient of Variation

$$\sqrt{VAR(X)}/E(X) = \sqrt{[\exp(\sigma^2) - 1]}$$

In order to fit the log-normal distribution to the input data, we must find values for μ and σ. On each figure of Figures 1-3, we are given the 50% confidence value. Its natural logarithm is equal to μ. To find the value of σ, we derived the normal equation for its regression only to find, after simplifications, the intractable result

$$\delta D/\delta\sigma = 0$$

$$= \sum_{i=1}^{n} [\, \Phi\{\Theta_i\} - P_i] \exp(-(1/2)\Theta_i^2)\, \Theta_i$$

where D is the sum of the squares of the differences between the log-normal distribution to be fit and the probabilities that were taken from the curves, Θ_i is equal to $[\log(x_i - \mu]/\sigma$, x_i is the ith cost point and P_i is the corresponding probability from the figure. To find the value of σ^*, the optimal estimate to minimize the differences, we searched over the values of σ. The results are given in Table 7. The data extracted from Figures 1-3 and used in the calculations leading to the values of σ are contained in Appendix B.

Table 7
Log-Normal Fits to Input Data

System	μ	σ	$\sqrt{VAR}/E(x)$
BSTS	ln(7.9)	0.12308	0.12355
SSTS	ln(8.7)	0.18352	0.18508
SBI	ln(14.3324)	0.28108	0.28672

Figure 8 compares the log-normal curve fit to the input data extracted from Figure 1 for the BSTS. Figures 9 and 10 similarly compare the curve fits to the data of Figures 2 and 3 for the SSTS and the SBI respectively.

We have characterized these three systems as representing three classes of risk: low, moderate and medium. We have applied these risk categories to each of the elements in the set of architectures investigated in ACES. The results of that application are given in Table 8.

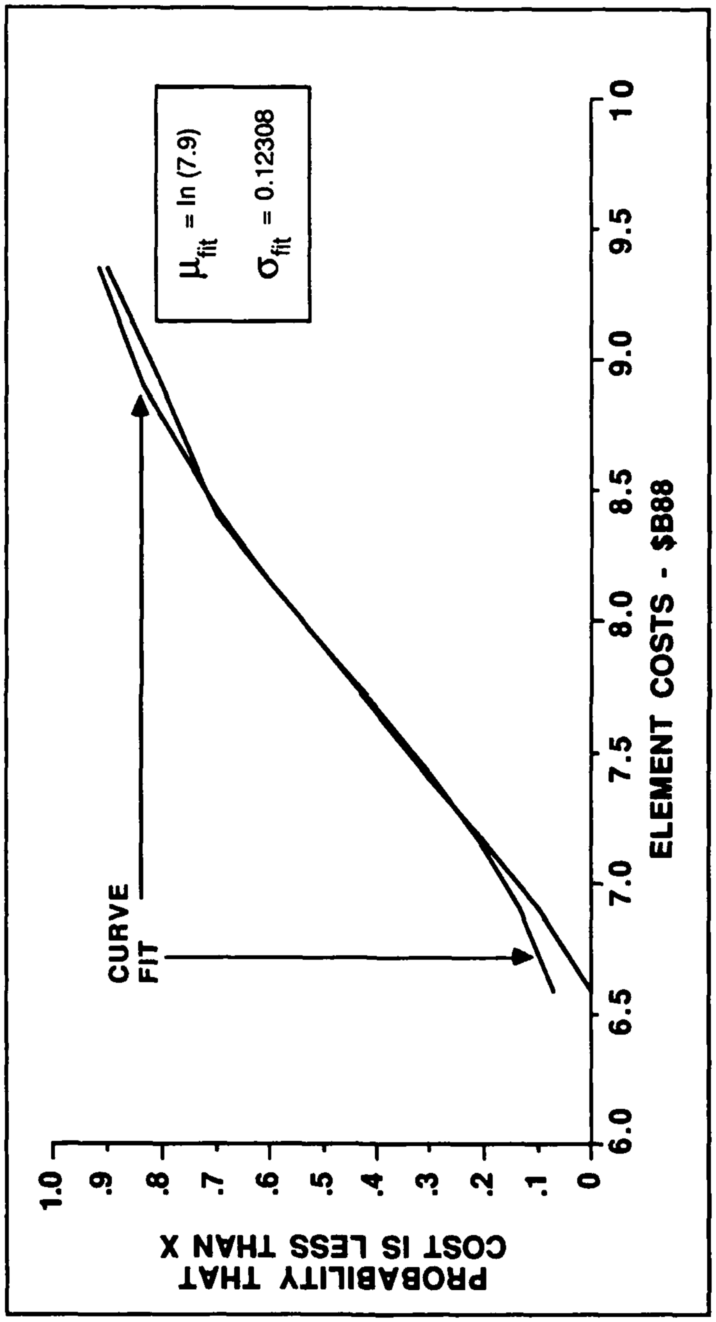

Figure 8. Comparison of Fitted Log Normal Distribution with Input Curve for BSTS

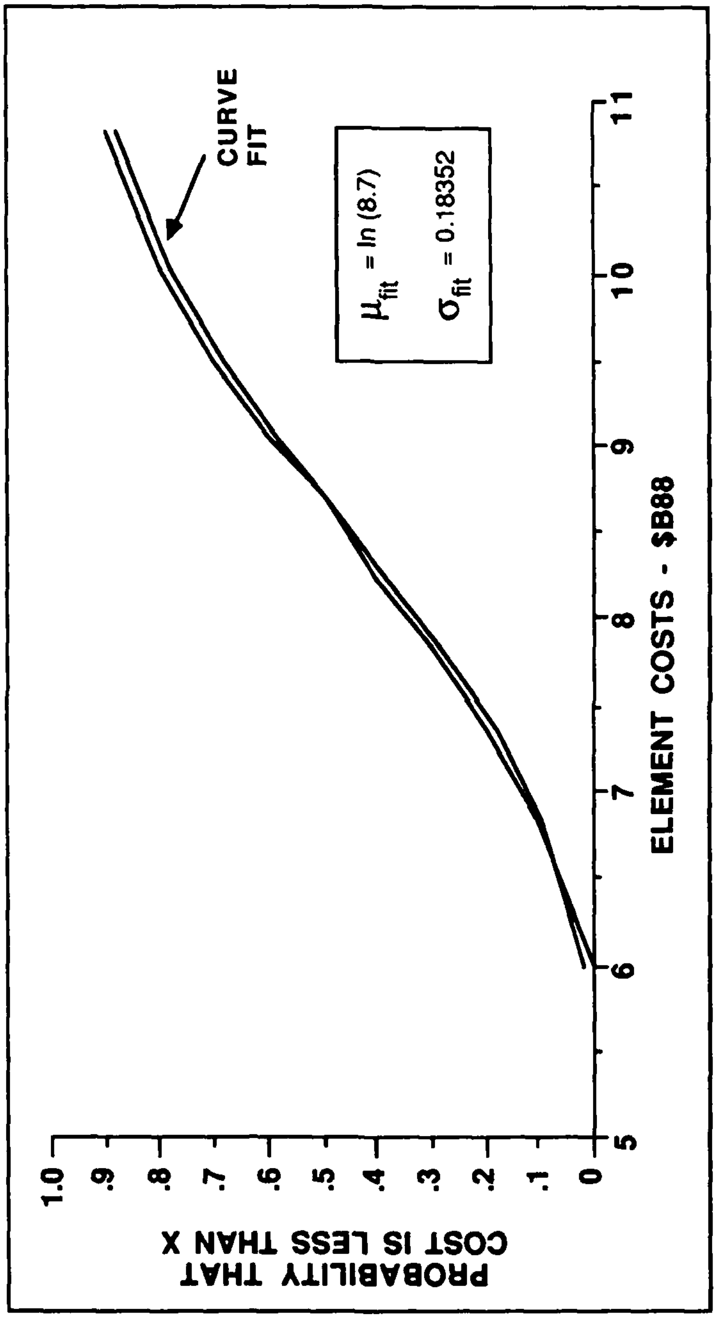

Figure 9. Comparison of Fitted Log Normal Distribution with Input Curve for SSTS

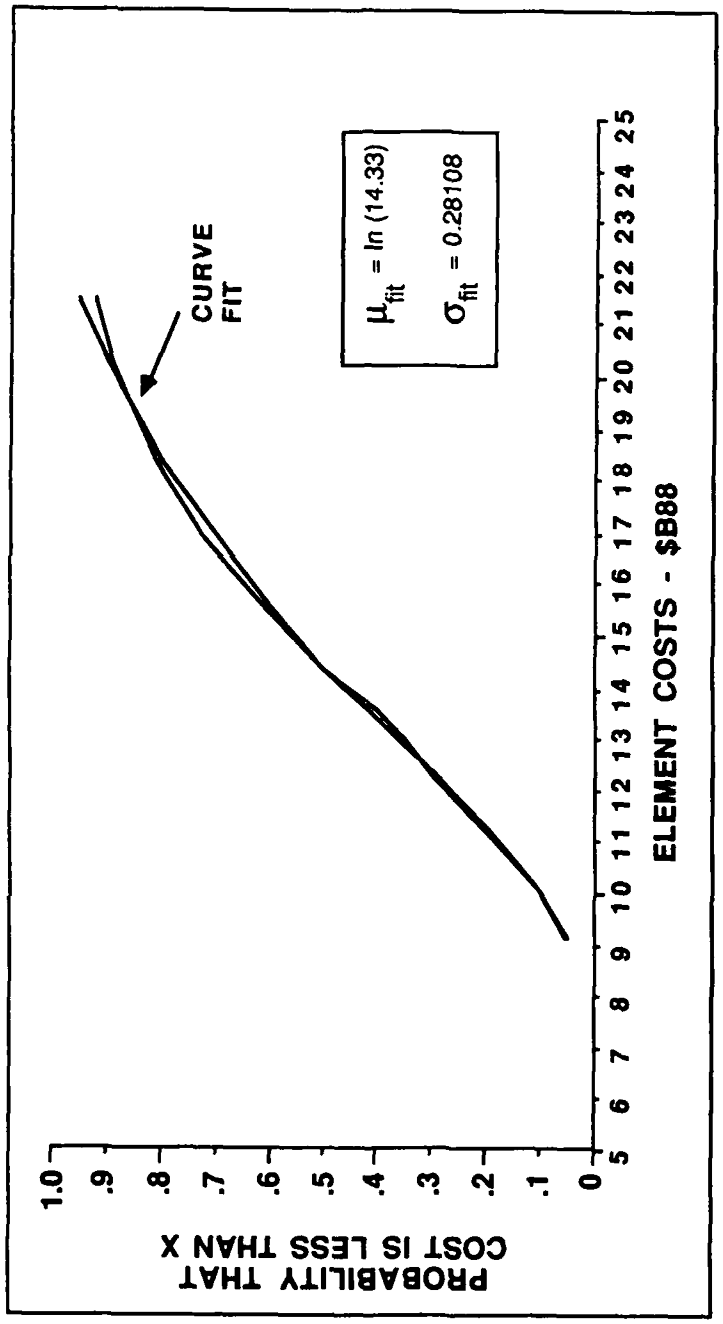

Figure 10. Comparison of Fitted Log Normal Distribution with Input Curve for SBI

Table 8
Risk Categories Assumed

System	System
Low Risk Category	Moderate Risk Category
BSTS	SSTS
GBR	GSTS
ERIS	
SEI	High Risk Category
LAUNCH	SBI
	CC/SOIF

Using these data and assumptions, we can now develop the total costs for each of the architectures. For the log-normal distributions, we have two procedures. In the first, we will take the input costs we have for R&D and Investment to be the 50% confidence estimates for each phase for each of the elements, devise their distributions according to the risk categories, and then sum those costs according to the rules we have developed for estimating the convolution of log-normal distributions. In the second procedure, we will take the input costs we have for R&D and Investment to be the expected value estimates for each phase for each element, and then proceed in the same manner as above.

In the first procedure, for each phase for the ith element, we assume that the inputs are C_{50}, the 50% confidence cost for the respective R&D and investment costs, and cv, the coefficient of variation for that element. We derive the parameters for the corresponding log-normal distribution as

$$\mu_i = \ln(C_{50})$$

$$\sigma_i = \sqrt{\ln(1+cv^2)}$$

For example, if the nominal costs for BSTS R&D are 5.4B$, if that 5.4B$ is equivalenced to C_{50}, and if it is in a low risk category, then

μ_1	=	$\ln(5.4) = 1.6864$	Derived from Nominal Costs
cv	=	0.12308	Taken from Risk Category
σ_1	=	$\sqrt{[\ln(1+cv^2)]}$	Derived from cv
		0.1226	

In the second procedure, for each phase for the ith element, we assume that the inputs are E(X), the expected value for the respective R&D and

investment costs, and cv, the coefficient of variation for that element. We derive the parameters for the corresponding log-normal distribution as

$$\sigma_i = \sqrt{\ln(1+cv^2)}$$
$$\mu_i = \ln[E(X)] - \sigma_i^2/2$$

For example, if the nominal costs for BSTS R&D are 5.4B$, if that 5.4B$ is equivalenced to E(X), and if it is in a low risk category, then

cv	=	0.12308	Taken from Risk Category
σ_1	=	$\sqrt{[\ln(1+cv^2)]}$	Derived from cv
		0.1226	
μ_1	=	$\ln(5.4) - \sigma_i^2/2$	Derived from Nominal Costs
	=	1.6789	

For the log-normal distribution, we approximate the convolutions by assuming that the convolution will yield (see Appendix A for justificiation of this approximation) a log-normal like distribution characterized by parameters whose values are derived from the sum of the expected values and variances. The algorithm is given as follows:

$$E(X) = \Sigma\, E(X_i)$$

$$\alpha = \ln[E(X)]$$

$$\beta = VAR(X) = \Sigma\, VAR(X_i)$$

$$\mu = 1/2\{4\alpha - \ln[\beta + \exp(2\alpha)]\}$$

$$\sigma = \sqrt{[2(\alpha-\mu)]}$$

where a and β are intermediate values, and μ and σ are the parameters of the resultant log-normal distribution for the total system costs.

We will use this algorithm to combine the costs for the R&D phase and the Investment phase, and to combine the costs for each of the elements. We will first develop the acquisition costs as the sum of the R&D and Investment costs for the elements that are deployed in an architecture. Then, we will develop the program costs as the sum of the R&D costs for all of the elements being considered for Phase One, either for immediate or slightly later deployment, and the investment costs for the elements to be immediately deployed.

RESULTS

Assuming the first procedure, that is, nominal costs are 50% confidence estimates, Table 9 presents a summary of the costs for each of the architectures. The supporting data tables presenting the sums of expected values and variances are illustrated in Appendix C for the DAB Architecture.

Table 9
Summary of Acquisition and Program Costs Derived with Independent Log-Normal Distributions Assuming Inputs are 50% Confidence Values of Cost

Acquisition Costs					
Probability	Architectures				
	ERIS	ERIS/HEDI	DAB	SBICV	BP
0.20	45	62	66	65	37
0.50	47	64	70	72	39
0.80	49	66	74	79	40

Program Costs					
Probability	Architectures				
	ERIS	ERIS/HEDI	DAB	SBICV	BP
0.20	55	69	69	75	46
0.50	58	71	73	81	48
0.80	60	74	77	88	50

Assuming the second procedure, that is, nominal costs are expected values, Table 10 presents the results of our calculations. The supporting data tables presenting the sums of expected values and variances are illustrated in Appendix D for the DAB Architecture.

Table 10
Summary of Acquisition and Program Costs Derived with Independent Log-Normal Distributions Assuming Inputs are Expected Values of Cost

Acquisition Costs

Probability		Architectures			
	ERIS	ERIS/HEDI	DAB	SBICV	BP
0.20	44	61	64	64	36
0.50	46	63	68	70	38
0.80	48	65	72	77	40

Program Costs

Probability		Architectures			
	ERIS	ERIS/HEDI	DAB	SBICV	BP
0.20	54	68	67	73	46
0.50	57	70	71	79	47
0.80	59	73	75	86	49

IV APPROACH USING NORMAL DISTRIBUTIONS

In this section, we derive the system costs assuming normal distributions as the distributions underlying the risk assessment data. The assumptions implicit in our approach are the following:

The costs (random variables) for each phase (R&D and Investment) for each element in an architecture are independent.

The probability function for the cost of a phase for an element has a normal distribution.

The nature of the cost distribution is constant by phase. We will represent this assumption by saying that the coefficient of variation remains constant.

The elements are divided into three categories: those with high risk, those with moderate risk, and those with low risk. Within a constant risk category, the coefficient of variation is the same.

Important relationships for the normal density function are given in Table 11.

Table 11
Normal Distribution Definitions

Density Function

$$f_X(x) = \exp\left[-(1/2)(x-\mu)^2/\sigma^2\right] / \left[\sqrt{(2\pi)}\,\sigma\right] \qquad -\infty < x < \infty, \quad -\infty < \mu < \infty, \quad \sigma > 0$$

Cumulative Distribution Function

$$F_x(x) = \Phi[(x-\mu)/\sigma]$$

Fifty Percent Confidence Value

$$X_{50} = \mu$$

Expected Value

$$E(X) = \mu$$

Variance

$$VAR(X) = \sigma^2$$

Mode

$$x^* = \mu$$

Coefficient of Variation

$$\sqrt{VAR(X)}/E(X) = \sigma/\mu$$

In order to fit the normal distribution to the input data, we must find values of μ and σ. On each figure of Figures 1-3, we are given the 50% confidence value. It is equal to μ. To find the value of σ, we derived the normal equation for its regression only to find, after simplifications, the intractable result

$$\delta D/\delta\sigma = 0$$

$$= \sum_{i=1}^{n} [\Phi(\Theta_i) - P_i] \exp(-(1/2)\Theta_i^2)$$

where D is the sum of the squares of the differences between the normal distribution to be fit and the probabilities that were taken from the curves, Θ_i is equal to $[x_i - \mu]/\sigma$, x_i is the ith cost point and P_i is the corresponding probability from the figure. To find the value of σ^*, the optimal estimate to minimize the differences, we searched over the values of σ. The results are given in Table 12. The data extracted from Figures 1-3 and used in the calculations leading to the values of σ are contained in Appendix B.

Table 12
Normal Fits to Input Data

System	μ	σ	σ/μ
BSTS	7.9	0.97241	0.1231
SSTS	8.7	1.58450	0.1821
SBI	14.3324	3.99300	0.2786

Figure 11 compares the normal curve fit to the input data extracted from Figure 1 for the BSTS. Figures 12 and 13 similarly compare the curve fits to the data of Figures 2 and 3 for the SSTS and the SBI respectively.

Using these data and assumptions, we can now develop the total costs for each of the architectures. For each phase for the ith element, we assume that the inputs are C_{50}, the 50% confidence cost for the respective R&D and investment costs, and cv, the coefficient of variation for that element. We derive the parameters for the corresponding normal distribution as

$$\mu_i = C_{50}$$

$$\sigma_i = \mu_i \, cv$$

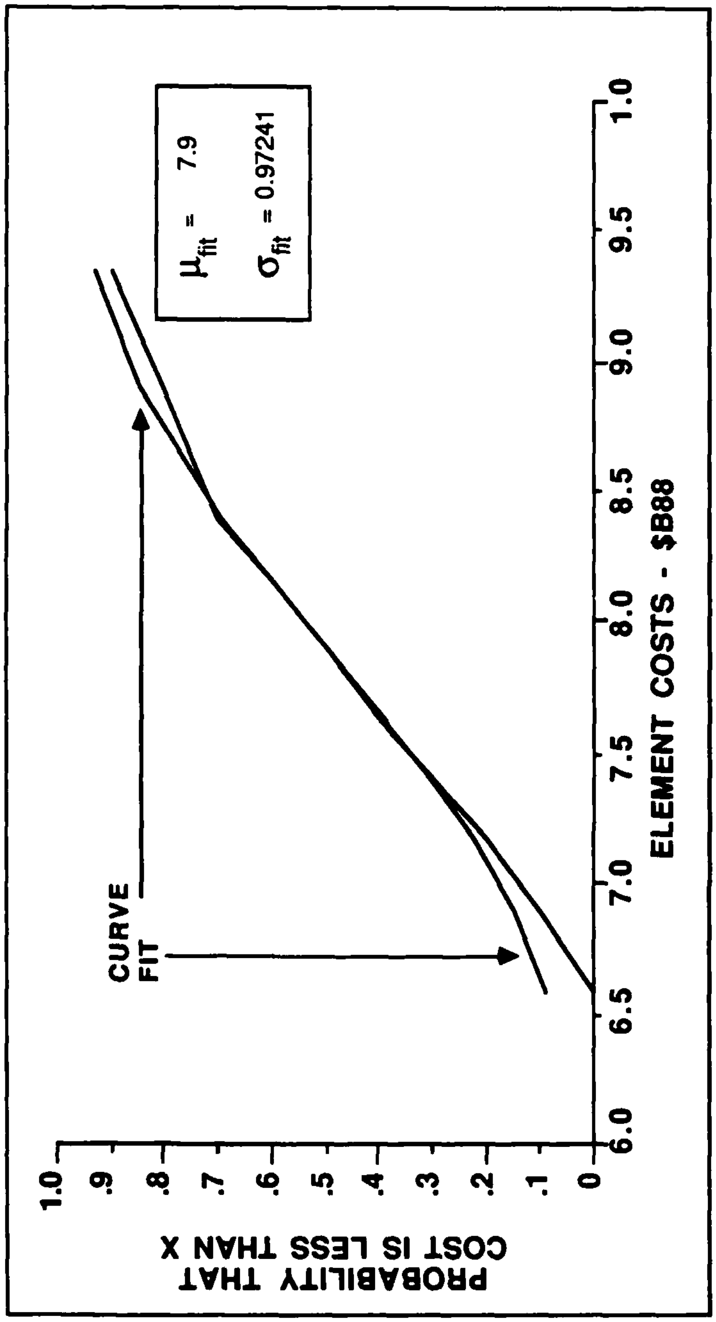

Figure 11. Comparison of Fitted Normal Distribution with Input Curve for BSTS

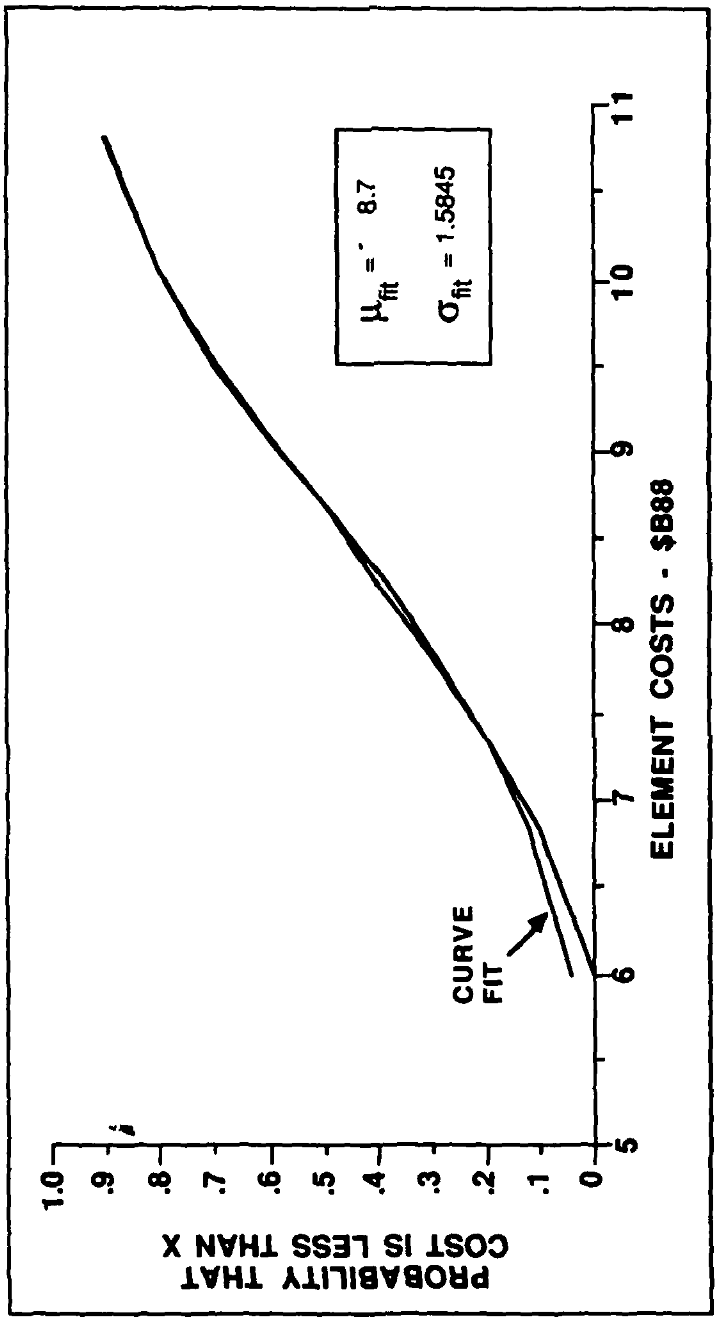

Figure 12. Comparison of Fitted Normal Distribution with Input Curve for SSTS

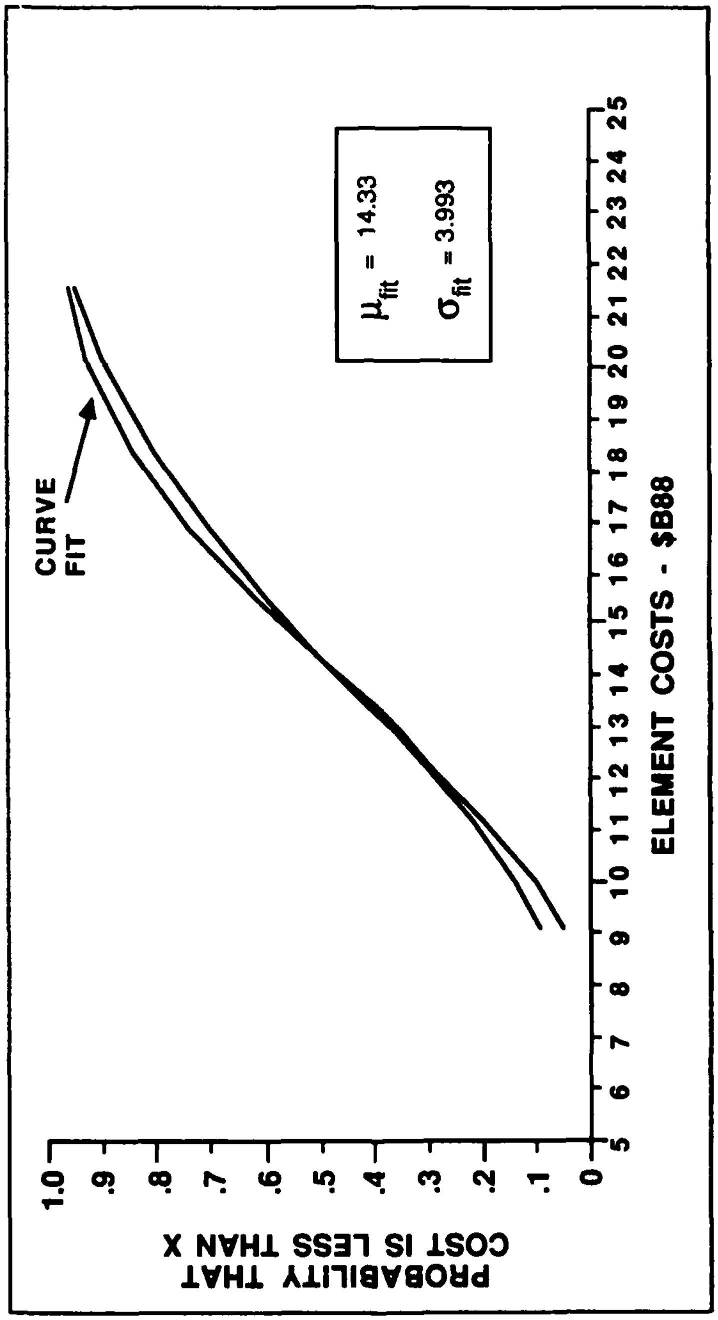

Figure 13. Comparison of Fitted Normal Distribution with Input Curve for SBI

For example, if the nominal costs for BSTS R&D are 5.4B$, if that 5.4B$ is equivalenced to C_{50}, and if it is in a low risk category, then

μ_1	=	5.4	Derived from Nominal Costs
cv	=	0.1231	Taken from Risk Category
σ_1	=	μ_1 cv	Derived from cv
	=	0.6647	

For the normal distribution, we have a closed form expression for the convolutions, which yield a normal distribution with the values for the two parameters being

$$\mu = E(X) = \sum E(X_i)$$

$$\sigma^2 = VAR(X) = \sum VAR(X_i)$$

We will use this algorithm to combine the costs for the R&D phase and the Investment phase, and to combine the costs for each of the elements.

Table 13 presents the results of our calculations. The supporting data tables illustrating the sums of expected values and variances are presented in Appendix E for the DAB Architecture.

Table 13
Summary of Acquisition and Program Costs Derived with Independent Normal Distributions

Acquisition Costs					
Probability	Architectures				
	ERIS	ERIS/HEDI	DAB	SBICV	BP
0.20	44	61	64	64	36
0.50	46	63	68	70	38
0.80	48	65	72	77	40

Program Costs					
Probability	Architectures				
	ERIS	ERIS/HEDI	DAB	SBICV	BP
0.20	54	68	68	73	46
0.50	57	70	72	80	48
0.80	59	73	75	86	50

V SENSITIVITIES TO ASSUMPTIONS

Recognizing that the range of values about the 50% confidence values is a lot less than we are accustomed to seeing, we began to examine some of our assumptions.

DIFFERENTIATING RISK ACCORDING TO PROGRAM PHASE

The first assumption we will investigate is the assumption that the risk distribution for R&D and Investment is the same. We will examine here the consequences of making an alternative assumption.

In developing a cost breakdown, the USA generally assigns some 15% of R&D and some 5% of the investment costs to risk mitigation. We will use these estimates to derive the variances of R&D and Investment programs from the coefficients of variations obtained from the USAF input data on total programs. (See Figures 1 through 3.) The problem is to find the standard deviations for an R&D program, σ_1, and Investment program, σ_2, when we know the expected values, μ_1 and μ_2 of these two phases, and when we know the coefficient of variation of the entire program. Seeing as how our disparate assumptions about the underlying distributions hardly affect our answers, we will work with the normal distribution since that is the easiest one to use. We can now state the problem as

Find σ_1 and σ_2 given μ_1, μ_2, cv, and the relationships

$$cv = \sigma/\mu$$

$$\frac{\sqrt{(\sigma_1^2 + \sigma_2^2)}}{\mu_1 + \mu_2} = cv$$

and

$$\sigma_1 / \mu_1 = 3\,\sigma_2 / \mu_2$$

where the unsubscripted variables apply to the combined program data.

A little algebra yields

$$\sigma_1 = 3\,\sigma_2\mu_1 / \mu_2$$

and

$$\sigma_2^2 = \frac{[cv\,(\mu_1 + \mu_2)\mu_2]^2}{9\,\mu_1^2 + \mu_2^2}$$

Replacing these different estimates of variation for the estimates that assumed both phases of a program were equal yields no significant difference. In Appendix F, we present the results for the DAB Architecture assuming the values of $\sigma 1$ and $\sigma 2$ defined above. Table 14 compares those data with the data obtained from Table 13.

Table 14
Comparison of Architecture Cost Ranges for Two Different Assumptions About the Split Between Program Phase Cost Variations

Acquisition Costs Prob	Assuming Equal Risks	Assuming 3:1 Risk Ratio	Differences
0.20	64.46	63.36	1.10
0.50	68.31	68.31	0.00
0.80	72.16	73.26	-1.10
Program Costs Prob	**Assuming Equal Risks**	**Assuming 3:1 Risk Ratio**	**Differences**
0.20	67.71	66.58	1.13
0.50	71.59	71.59	0.00
0.80	75.47	76.60	-1.13

COMPUTING COST ESTIMATES ASSUMING PROGRAM INTERDEPENDENCIES

The second assumption we will investigate is independence. In the earlier sections, we assumed that the costs for the phases of a program element, that is, the cost distributions for the R&D and Investment phases, were independent one from another, and that all of the program elements were also independent one from another. It is to these assumptions that we owe the tractability of analysis of the log-normal distributions and the ease of the analysis for the normal distribution. Here, in this subsection, we examine possible implications of interdependencies by assuming that the program phases and the program elements may not be independent.

IMPACT OF CORRELATION WITHIN A PROGRAM. Assuming that the underlying distributions are normal, but **correlated,** we derive the distribution for the sum of the R&D cost and the Investment cost and factor that into the total system costs. To do so, we further assume that the correlation coefficient, ρ, is known. If we let X_1 be the random R&D costs,

normally distributed with mean μ_1 and variance σ_1 and X_2 be the random Investment costs, normally distributed with mean μ_2 and variance σ_2, and Z_i, their sum for the ith program element, then Z_i is normally distributed with parameters

$$E(Z_i) = \mu_1 + \mu_2$$
$$VAR(Z_i) = \sigma_1^2 + \sigma_2^2 + 2\rho\sigma_1\sigma_2$$

Provided that we make the assumption that we know the mean and the variance of the distributions for the costs of the two phases, (actually determined for this exercise by analogy to Figures 1-3 and through the coefficient of variation) then we can first compute the distributions of the costs for the individual programs, taking into account the correlations, and then compute the total system cost distributions (assuming still that the program elements are independent). For the DAB Architecture, the 20% confident, 50% confident and 80% confident costs are presented in Figure 14 as a function of the assumed correlation coefficient. (In generating this plot, note that we have assumed that the correlation coefficient between R&D and Investment is the same for all program elements.)

IMPACT OF PROGRAM CORRELATION. Assuming that the underlying program element distributions are normal, but that they are correlated with one another, we can also derive the distribution for the total system costs. To do this we must know the covariance matrix, that is, the correlations of the cost distributions for each program element with the cost distributions of each of the other program elements in the system. As above, we will assume that we know the covariance matrix. For our sensitivity analysis, we will assume that the correlation coefficient between any two programs is identical to ρ, that is, $COV[Zi,Zj] = \rho\sigma i\sigma j$. If we let Z be the total system costs, then Z is normally distributed with parameters

$$E(Z) = \sum_{i=o}^{n} E(Z_i)$$

$$VAR(Z) = \sum_{i=o}^{n} \sum_{j=o}^{n} COV[Z_i, Z_j]$$

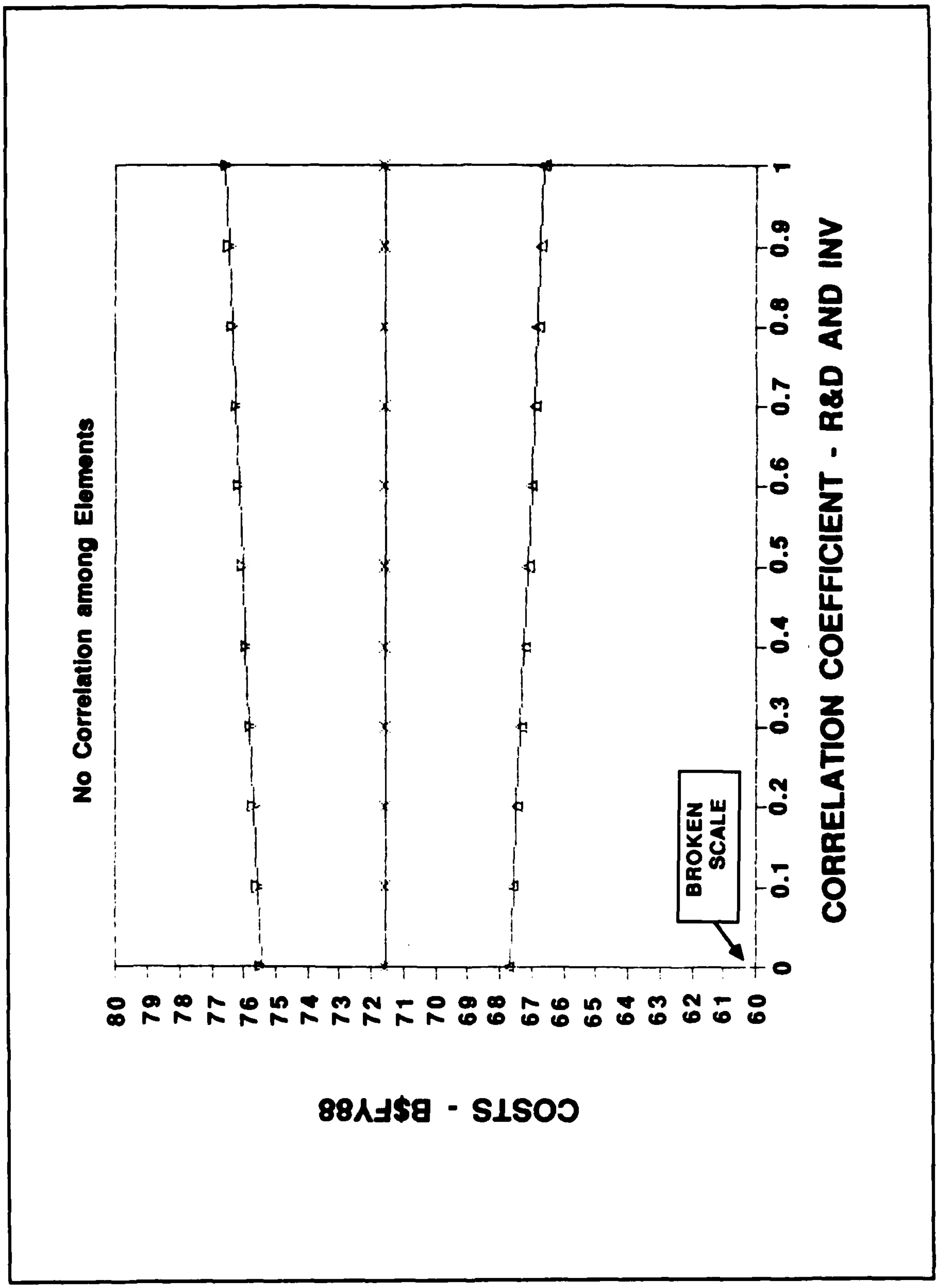

Figure 14. Program Costs for DAB Architecture

where n is the number of program elements whose costs are to be summed for the acquisition or program costs.

For the DAB Architecture, we plot in Figure 15 the 20%, 50% and 80% confident costs for the total acquisition costs and in Figure 16 the same quantities for the total program costs.

For the calculations in Figures 15 and 16, we have assumed that the correlation coefficient between R&D and Investment cost distributions is equal to 0.50.

Just as a further point of reference, consider the following comparison. For a correlation coefficient of unity for the correlation between programs and a correlation coefficient of 0.5 for the correlation between R&D and Investment, the program costs were estimated at 81B$. If we assumed unity for both correlation coefficients, the program costs were estimated at 82.1B$.

Just as a bound to use with these results, consider the cost of the acquisition for the DAB architecture, derived assuming that the total acquisition costs had the same coefficient of variation we assumed for the SBI program. That cv was 0.2786. Given the mean value of the acquisition as 68B$, the standard deviation should be 18.95 B$. AT 20% confidence, the acquisition costs we calculate should be more than 52.1B$. AT 80% confidence, the acquisition costs should be less than 84.0B$. Obviously, the 50% confident number is still 68B$. Note that the costs we have derived in Figure 15 for the acquisition costs for the fully correlated case are within those bounds.

COST ESTIMATES WITH LARGER VARIANCES. We note that the costs bounds just developed, assuming full correlations between programs, are still tight relative to what might be expected. For a program that is at this stage of its development and still requires advances in technology, some might expect that the cost ranges should be broader than that, for example, the upper value of the range being something like twice the lower value. However, the procedure we have applied here seems consistent with what we know, and uses our current best estimates of the variations.

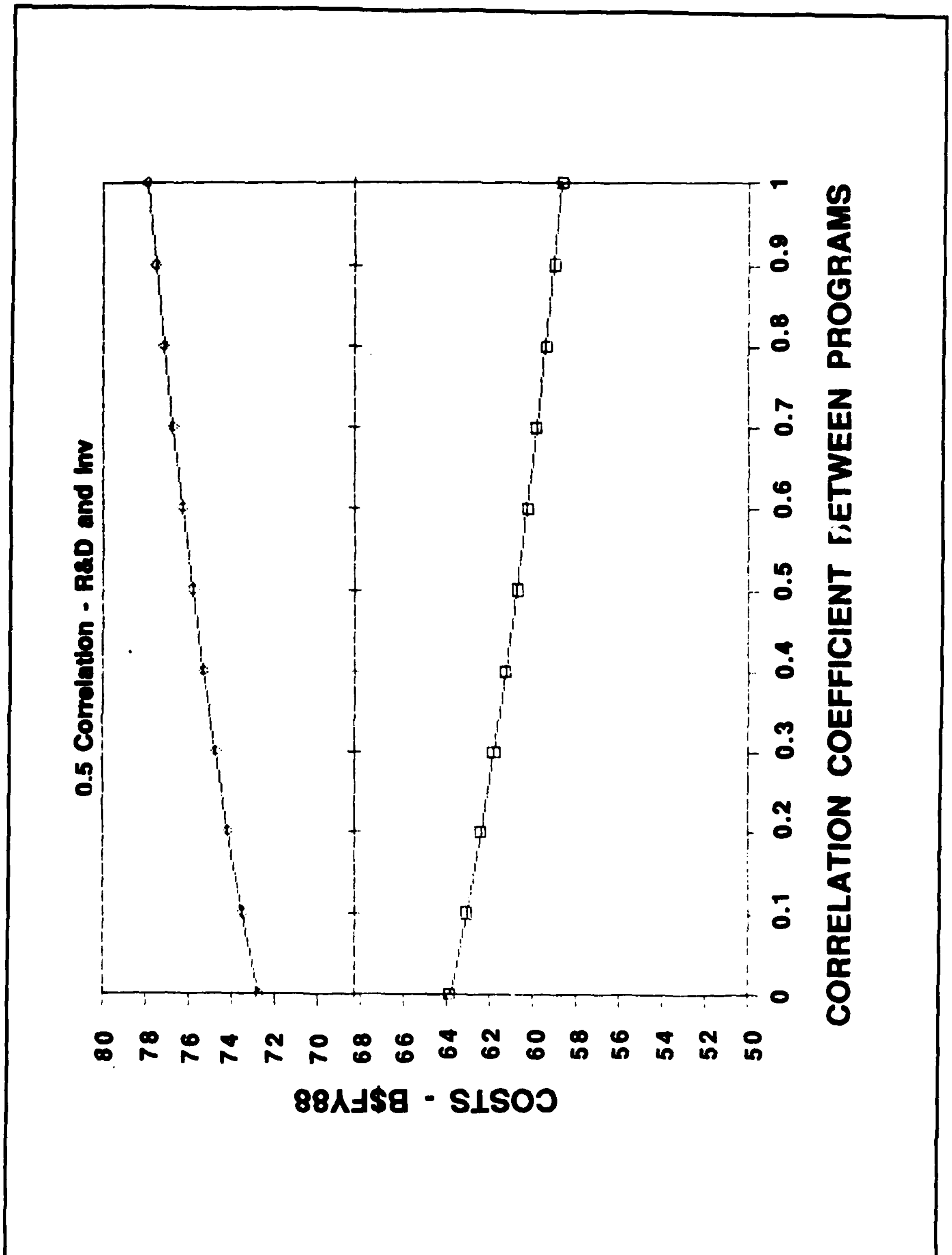

Figure 15. Acquisition Costs for DAB Architecture

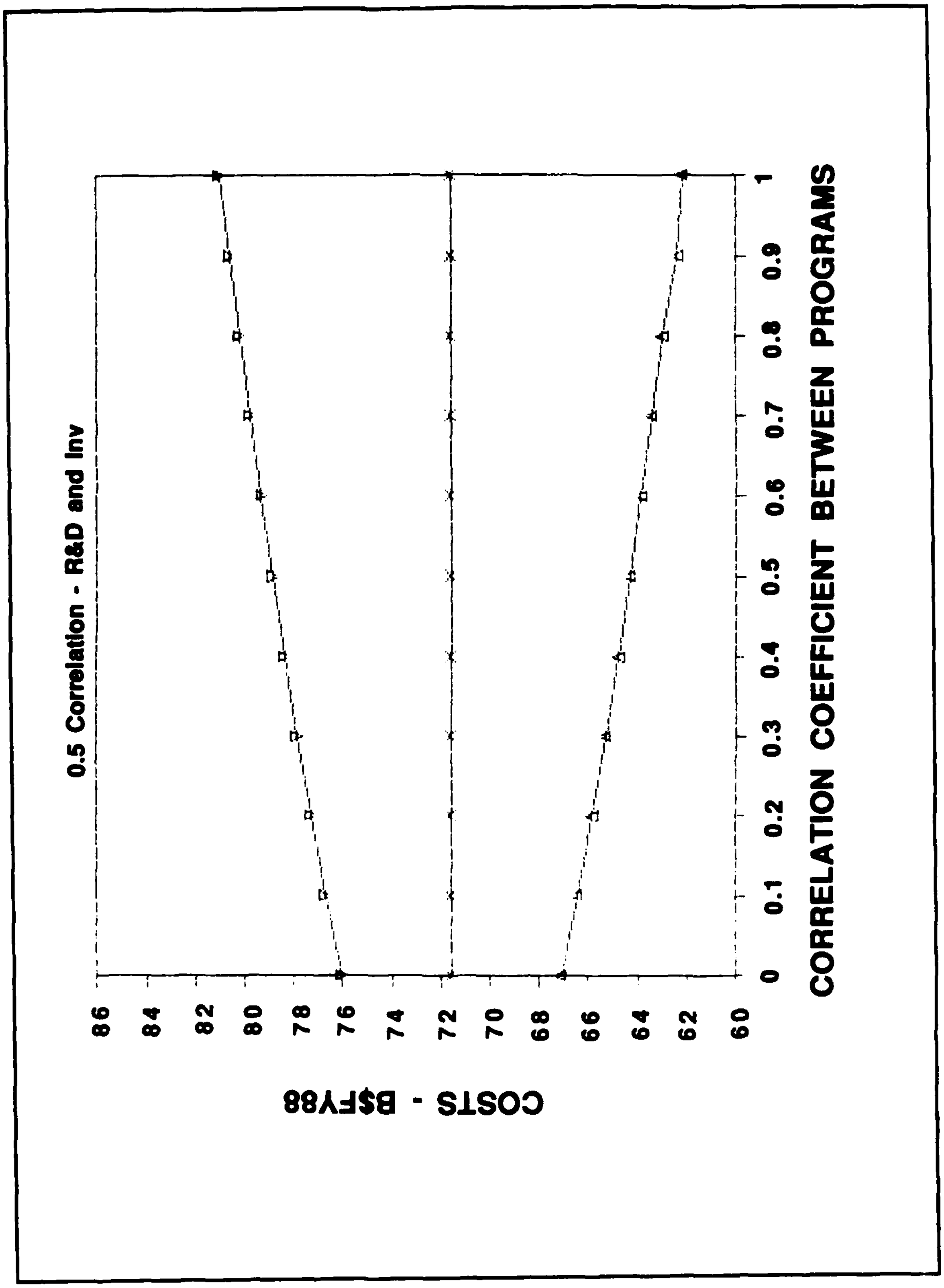

Figure 16. Program Costs for DAB Architecture

We have experimented (made mistakes in our inputs) with larger variances for the log-normal distributions and obtained instances where the range of values (ratio of 80% confident values to 20% confident values) did have close to a factor of two between them (for the DAB architecture, we manufactured a case where the lower -- 20% confidence -- was 62B$ and the upper bound -- 80% confidence -- was 109B$). However, the variances we used to get those results were much larger than any we are currently deriving from Figures 1-3. Just to illustrate, the coefficient of variation we used to obtain the almost 2:1 range with the log-normal distribution were, for the low risk elements, 0.1215, for the moderate risk elements, 0.3031, and for the high risk elements, 1.2258. These can be compared with the coefficient of variation we are now using with the log-normal distribution: 0.12136 for the low risk elements, 0.1851 for the moderate risk elements, and 0.2867 for the high risk elements. There had to be a factor of two increase in the variation for the moderate risk elements and a factor of four increase in the variation of the high risk elements for us to find a value close to the 2:1 ratio between the upper and lower bounds.

If the cost ranges are to reflect a higher ratio than we have found here in this report, then the input estimates of variation must increase. This, of course, will not set well with program managers. On the other hand, the cost variations we include do not include the many sources of variation that come from outside a program manager's control, but still typically increase the costs of a program element: politically inspired delays, mission changes and threat modifications. Incorporating these variations, if we could, would significantly increase the variation, and the range of estimates we would find.

Appendix A

Log-Normal Distributions

Appendix A

Log-Normal Distributions

The purpose of this appendix is to present some features of the log-normal distribution. The notation is taken from Ref A-1.

Though there are a number of alternative expressions for the density function of the log-normal distribution, the form of the log-normal density function we will use here is given by

$$f_X(x) = \exp\left[-(1/2)\,(\ln x - \mu)^2/\sigma^2\right] / \left[\sqrt{(2\pi)}\,\sigma x\right] \quad 0 < x < \infty$$

This density function is also a function of the values of the two parameters, μ and σ, whose features we will explore below.

The log-normal cumulative distribution function is then

$$F_X(x) = \int_0^x \exp\left[-(1/2)\,(\ln y - \mu)^2/\sigma^2\right] dy / \left[\sqrt{(2\pi)}\,\sigma y\right]$$

We can transform this equation by substituting

$$u = (\ln y - \mu)/\sigma$$
$$du = dy/(\sigma y)$$

to obtain

$$F_X(x) = \int_{-\infty}^{(\ln x-\mu)/\sigma} \exp\left[-(1/2)u^2\right] du / \sqrt{(2\pi)}$$

which is equivalent to

$$F_X(x) = \Phi\left[(\ln x-\mu)/\sigma\right]$$

where $\Phi(x)$ is the cumulative standard normal function.

The Expected Value of x, E(X), is given by

$$E(X) = \int_0^\infty x \exp\left[-(1/2)\,(\ln x - \mu)^2/\sigma^2\right] dx / \left[\sqrt{(2\pi)}\,\sigma x\right]$$

Again substituting

$$u = (\ln x - \mu)/\sigma$$

$$du = dx/(\sigma x)$$

$$\exp(\sigma u + \mu) = x$$

we obtain

$$E(X) = \int_{-\infty}^{\infty} \exp(\sigma u+\mu) \exp[-(1/2)u^2] \, du / \sqrt{(2\pi)}$$

$$E(X) = \int_{-\infty}^{\infty} \exp[-(1/2)(u^2 -2\sigma u - 2\mu)] \, du / \sqrt{(2\pi)}$$

$$E(X) = \int_{-\infty}^{\infty} \exp[-(1/2)(u^2 -2\sigma u + \sigma^2 - \sigma^2 - 2\mu)] \, du / \sqrt{(2\pi)}$$

$$E(X) = \int_{-\infty}^{\infty} \exp[-(1/2) \{(u - \sigma)^2 - (\sigma^2 + 2\mu)\}] \, du / \sqrt{(2\pi)}$$

$$E(X) = \int_{-\infty}^{\infty} \exp[-(1/2) (u - \sigma)^2] \exp[(1/2)(\sigma^2 + 2\mu)] \, du / \sqrt{(2\pi)}$$

$$E(X) = \exp[(1/2)(\sigma^2 + 2\mu)] \int_{-\infty}^{\infty} \exp[-(1/2) (u - \sigma)^2] \, du / \sqrt{(2\pi)}$$

$$E(X) = \exp[(1/2)(\sigma^2 + 2\mu)]$$

The <u>Second Moment</u> of x, $E(X^2)$, is given by

$$E(X^2) = \int_{0}^{\infty} x^2 \exp [-(1/2) (\ln x - \mu)^2/\sigma^2] \, dx / [\sqrt{(2\pi)} \, \sigma x]$$

Again substituting

$$u = (\ln x - \mu)/\sigma$$
$$du = dx/(\sigma x)$$
$$\exp(\sigma u + \mu) = x$$

we obtain

$$E(X^2) = \int_{-\infty}^{\infty} \exp[2(\sigma u+\mu)] \exp[-(1/2)u^2] \, du / \sqrt{(2\pi)}$$

$$E(X^2) = \int_{-\infty}^{\infty} \exp[-(1/2)\{u^2-4\sigma u-4\mu\}] \, du / \sqrt{(2\pi)}$$

$$E(X^2) = \int_{-\infty}^{\infty} \exp[-(1/2)\{u^2-4\sigma u+4\sigma^2-4\sigma^2-4\mu\}] \, du / \sqrt{(2\pi)}$$

$$E(X^2) = \int_{-\infty}^{\infty} \exp[-(1/2)(u-2\sigma)^2] \exp[2\sigma^2+2\mu] \, du / \sqrt{(2\pi)}$$

$$E(X^2) = \exp[2\sigma^2+2\mu] \int_{-\infty}^{\infty} \exp[-(1/2)(u-2\sigma)^2] \, du / \sqrt{(2\pi)}$$

$$E(X^2) = \exp[2\sigma^2+2\mu]$$

The Variance of X is given by

$$\mathrm{VAR}(X) = E(X^2) - E^2(X)$$
$$= \exp[2\sigma^2+2\mu] - \exp[\sigma^2 + 2\mu]$$
$$= \{\exp[2\sigma^2] - \exp[\sigma^2]\} \exp[2\mu]$$

The Mode of the distribution is obtained by finding the value of x which makes the derivative of the density function equal to zero. Setting

$$f'_X(x) = -\sqrt{(2\pi)} \{(\ln x-\mu)/\sigma + \sigma\} \exp[-(1/2)(\ln x-\mu)^2/\sigma^2] = 0$$

we have for the mode at x^*

$$(\ln x^* - \mu)/\sigma = -\sigma$$

or

$$x^* = \exp(\mu - \sigma^2)$$

The <u>coefficient of variation</u> is defined as the ratio of the standard deviation ($\sqrt{VAR(X)}$) to the expected value (E(X)). We are using it here as a standard deviation normalized by the mean. We illustrate in Figure A-1 the similarity of five different log-normal distributions which have the the same coefficient of variation, but have with values of $\exp(\mu)$ ranging from 5 to 9 in steps of one. The similarity between the resulting cumulative distributions is obvious. Though the σ parameter remains constant, the variance does not: it increases as μ increases.

Using the multiplicative property of exponents, the square root of the variance becomes

$$\sqrt{VAR(X)} = \exp(\mu)[\exp(2\sigma^2) - \exp(\sigma^2)]^{(1/2)}$$

Expressing the expected value as a product of two exponential terms, we can rewrite it as

$$E(X) = \exp(\mu)\exp(\sigma^2/2) = \exp(\mu)\,[\exp(\sigma^2)]^{(1/2)}$$

The ratio of the two equations above yields for the coefficient of variation, cv,

$$\sqrt{VAR(X)}/E(X) = \{\,[\exp(2\sigma^2) - \exp(\sigma^2)\,]\exp(-\sigma^2)\,\}^{(1/2)}$$

$$= [\,\exp(\sigma^2) - 1\,]^{(1/2)} = cv$$

This equation can be turned around to provide a value for σ if the coefficient of variation is known.

$$\sigma = \sqrt{\ln(1+cv^2)}$$

This equation does not have an explicit dependence on μ.

We note in Table A-1 the value of the log normal cumulative distribution function for several of the key values of x.

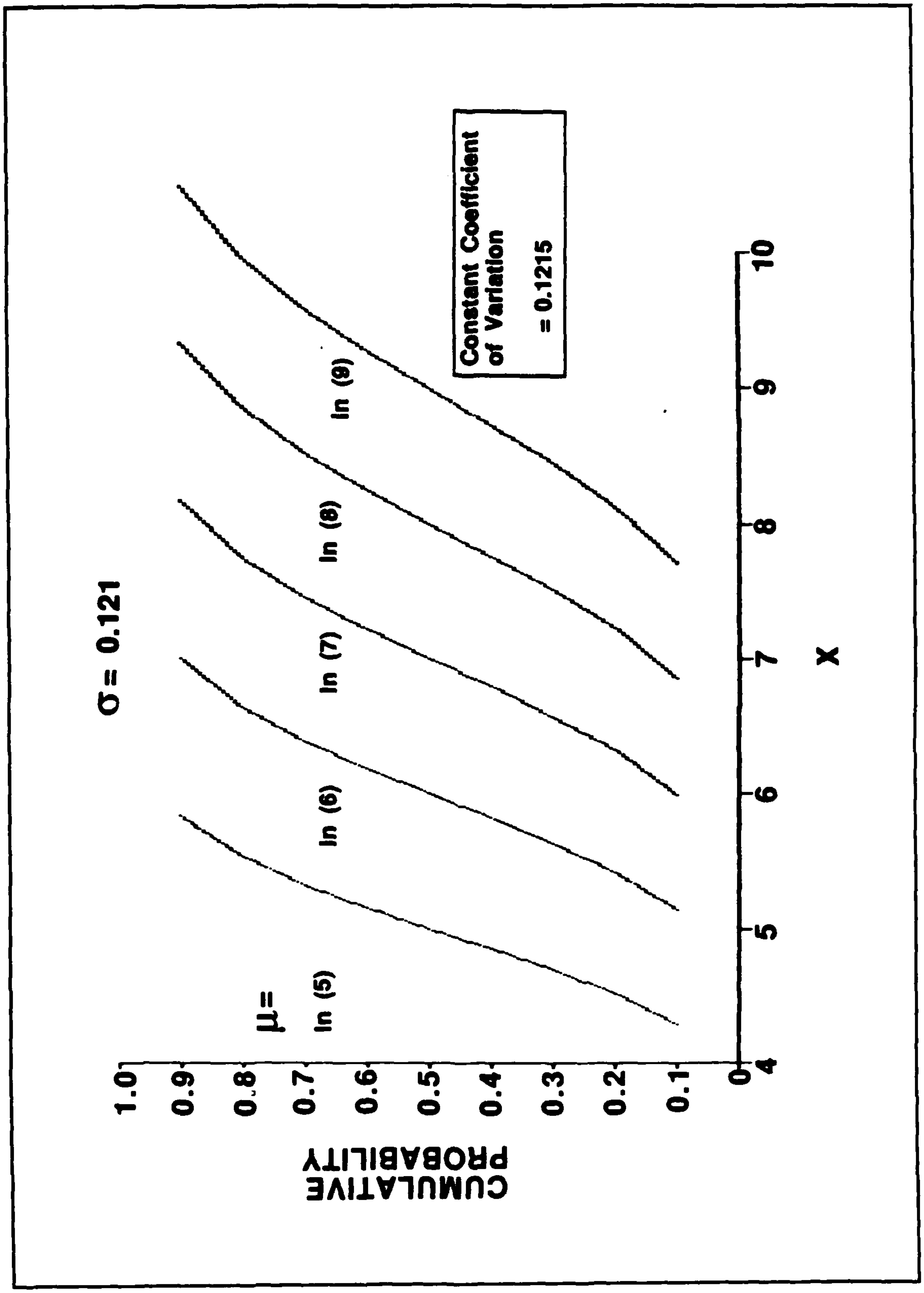

Figure A-1. Comparison of Log Normal Risk Distributions

Table A-1
Log-Normal Function Values

x	$F_X(x)$
$E(X)=\exp[\mu+(1/2)\sigma^2]$	$\Phi(-\sigma/2)$
$\text{Mode}(X)=\exp(\mu-\sigma^2)$	$\Phi(-\sigma)$
$\exp(\mu-1.2801\sigma)$	0.10
$\exp(\mu-0.8391\sigma)$	0.20
$\exp(\mu-0.5216\sigma)$	0.30
$\exp(\mu-0.2513\sigma)$	0.40
$\exp(\mu)$	0.50
$\exp(\mu+0.8391\sigma)$	0.80
$\exp(\mu+1.6445\sigma)$	0.95
$\exp(\mu+2.3276\sigma)$	0.99

If I have two independent random variables with log-normal distributions, say X_1 and X_2, and I want to determine the distribution of the sum of two log-normals, $Z = X_1+X_2$, I could proceed with either the method of convolutions or of characteristic functicns. However, since I could make neither of these methods yield tractable expressions, I have fallen back on the following approximation: I have assumed that the resulting distribution has a log-normal distribution with parameters μ and σ determined from the distributions of the variables to be added together. I now need only to determine those values.

Since I have assumed that the distributions are independent, I know the following to be true

$$E(Z) = E(X_1) + E(X_2)$$
$$VAR(Z) = VAR(X_1) + VAR(X_2)$$

Since I have assumed that all distributions are log-normal, I also know the dependencies of each of these quantities on their respective parameters. Thus, for the sum of two log-normal distributions, I can write

$$E(Z) = \exp(\mu + (1/2)\sigma^2) = \exp(\mu_1 + (1/2)\sigma_1^2) + \exp(\mu_2 + (1/2)\sigma_2^2) = A$$

$$
\begin{aligned}
VAR(Z) &= \exp(2\mu)[\exp(2\sigma^2)-\exp(\sigma^2)] \\
&= \exp(2\mu_1)[\exp(2\sigma_1{}^2)-\exp(\sigma_1{}^2)] \\
&\qquad + \exp(2\mu_2)[\exp(2\sigma_2{}^2)-\exp(\sigma_2{}^2)] \\
&= \beta
\end{aligned}
$$

The subscripted variables are assumed known and fixed and thus the expressions yield constants, A and β, from which we must determine μ and σ. We can write σ in terms of μ by taking the logarithm of both sides of the first equation and manipulating the result:

$$\ln[\exp(\mu + (1/2)\sigma^2)] = \ln[A] = \alpha$$

$$\mu + (1/2)\sigma^2 = \alpha$$

$$\sigma^2 = 2(\alpha - \mu)$$

Substituting for σ^2 in the expression for the variance of Z we obtain

$$\exp(2\mu)\ [\ \exp\{4(\alpha-\mu)\} - \exp\{2(\alpha-\mu)\}\ ] = \beta$$

Multiplying through by the exponent outside the brackets on the left

$$\exp\{4\alpha-2\mu\} - \exp\{2\alpha\} = \beta$$

Taking the logarithm of both sides

$$\{4\alpha-2\mu\} = \ln(\beta + \exp\{2\alpha\})$$

Manipulating the resulting expression

$$\mu = (1/2)[\ 4\alpha - \ln(\beta + \exp\{2\alpha\})\ ]$$

With μ known, we can also solve for σ.

We illustrate the quality of the approximation with several examples of distributions of sums of log-normals. Let us assume the two log-normal variables have distributions with the parameters given in Table A-2.

Table A-2
Parameter Values for First Example

Parameter	X_1	X_2
μ_i	ln8	ln5
σ_i	1	1
E(X)	13.19	8.24
VAR(X)	298.93	116.77
A		21.43
α		3.06
β		415.70
μ		2.743 = ln15.52
σ		0.803

To test the quality of the approximation, we show in Figure A-2 the convolution of the two distributions (computed numerically) with the curve generated by the approximation. As it turns out, the approximation looks fair. This quality of fit suggests that there is something very much like a log-normal result to the convolution.

We tried a second example as well. The parameters are given in Table A-3. The two products, one a numerical convolution and the other the product of our approximation, are presented in Figure A-3. Again, the fit is very close.

Table A-3
Parameter Values for Second Example

Parameter	X_1		X_2
μ_i	ln8		ln5
σ_i	0.50		0.50
E(X)	9.06		5.67
VAR(X)	23.34		9.12
A		14.73	
αa		2.69	
β		32.46	
μ		2.620 = ln13.739	
σ		0.373	

Finally, in Table A-4, we present an example that approximates some of the values assumed for σ_i in the body of the report. In Figure A-4, we compare the approximation with the numerical convolution. The result is a perfect fit within the resolution of the graph.

Table A-4
Parameter Values for Third Example

Parameter	X_1		X_2
μ_i	ln8		ln5
σ_i	0.10		0.10
E(X)	8.04		5.03
VAR(X)	0.65		0.25
A		13.06	
a		2.57	
β		0.90	
μ		2.567 = ln13.03	
σ		0.077	

The three examples given above suggest (and do no more than that) that our approximation is good enough for an estimate of the convolution of two log-normal distributions. When we are adding the results from several, we will assume that the approximation holds good. However, we could also assume that the sum of a large number of log-normal distributions will result in an approximately normal distribution by the central limit theorem.

The relationship between the log-normal and the normal distribution becomes apparent through the transformation

$$z = \ln x$$

By Ref A-2, we have that if

$$z = g(x)$$

then

$$f_z(z) = \sum f_x(x_i) / |g'(x_i)|$$

where x_i are all the real roots associated with the value of z and where $g'(x)$ is the derivative of $g(x)$ with respect to x.

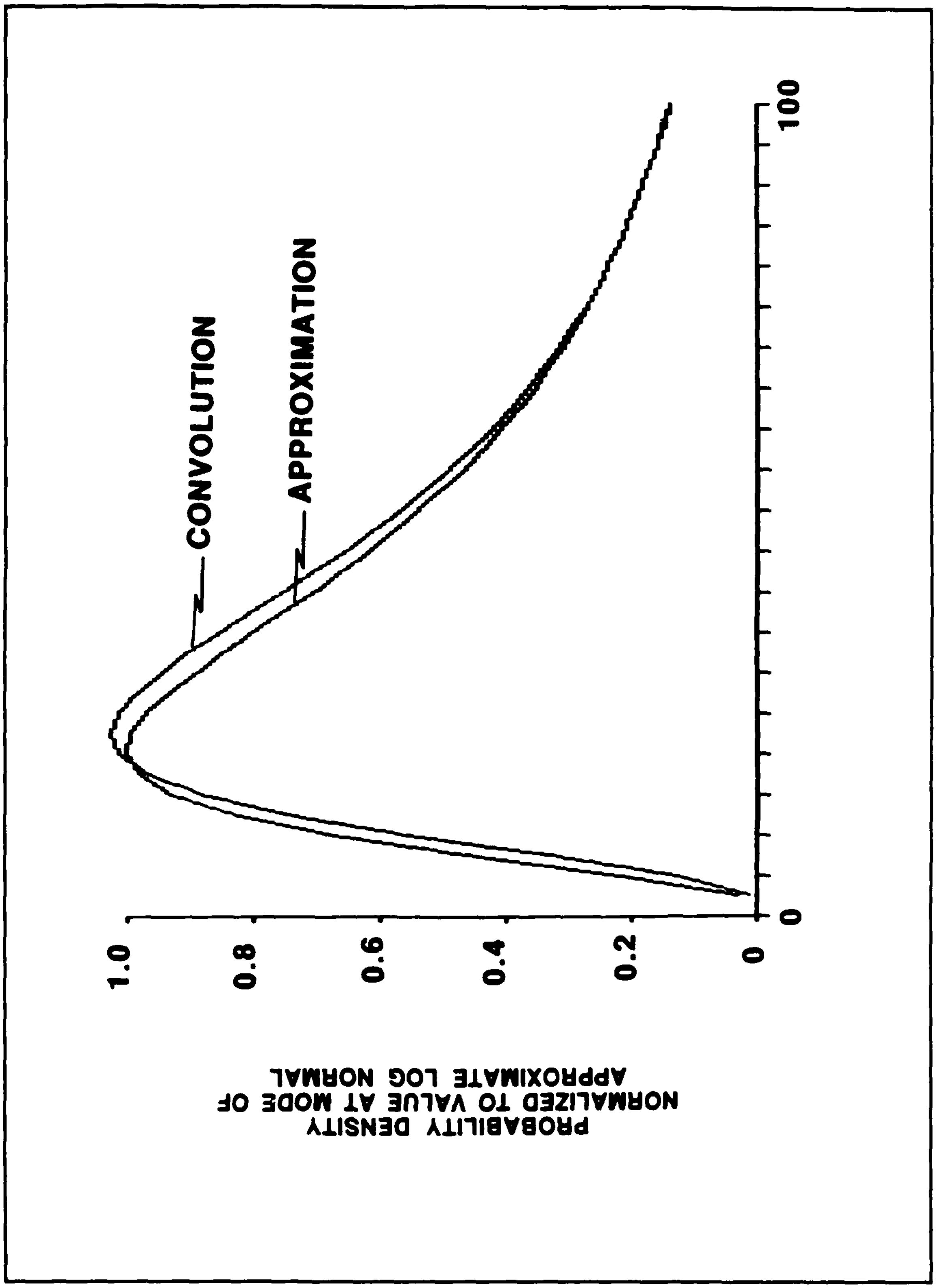

Figure A-2. Comparison of Computer Convolution and Approximation for Thrid Example

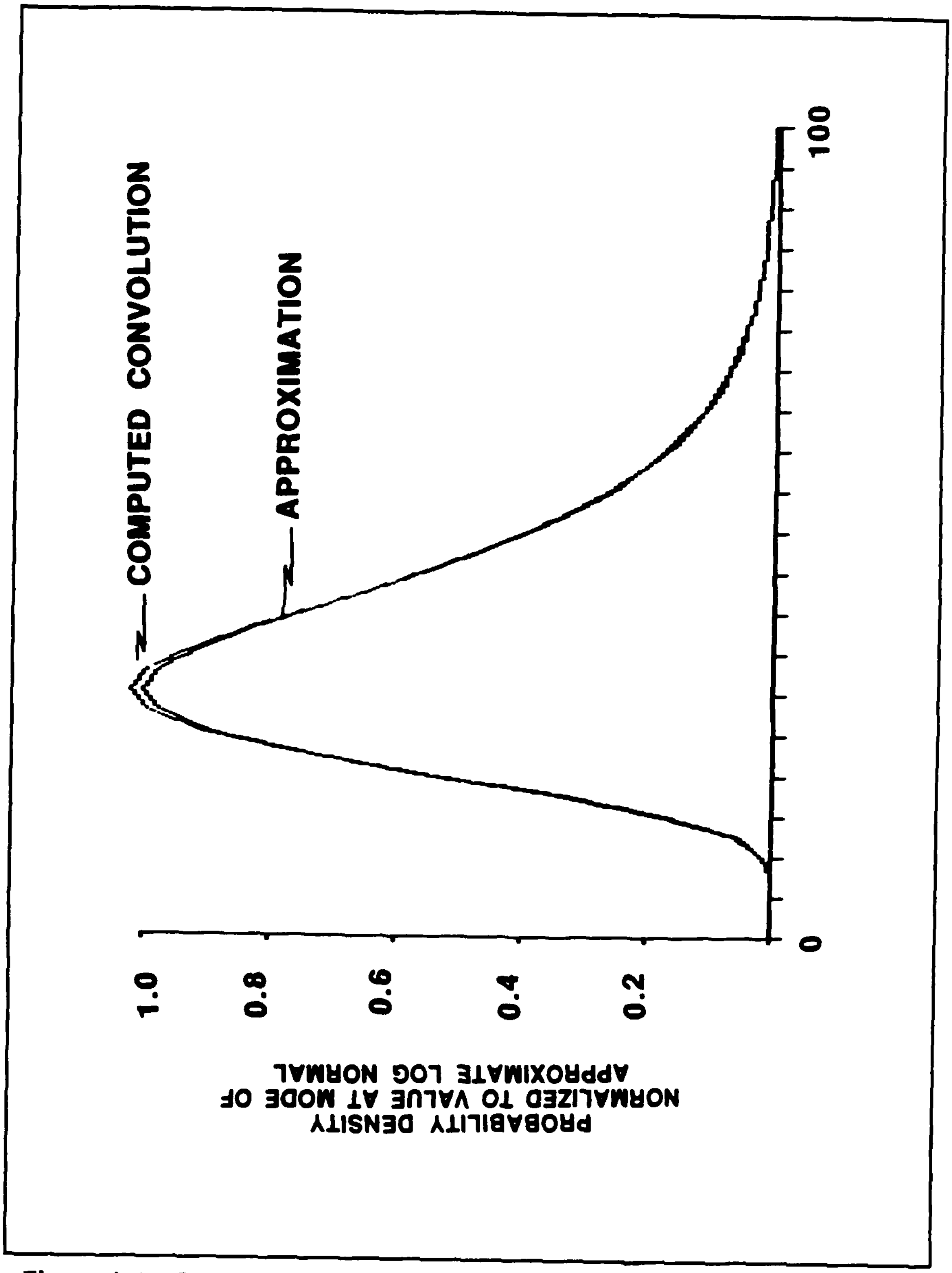

Figure A-3. Comparison of Computer Convolution and Approximation for Second Example

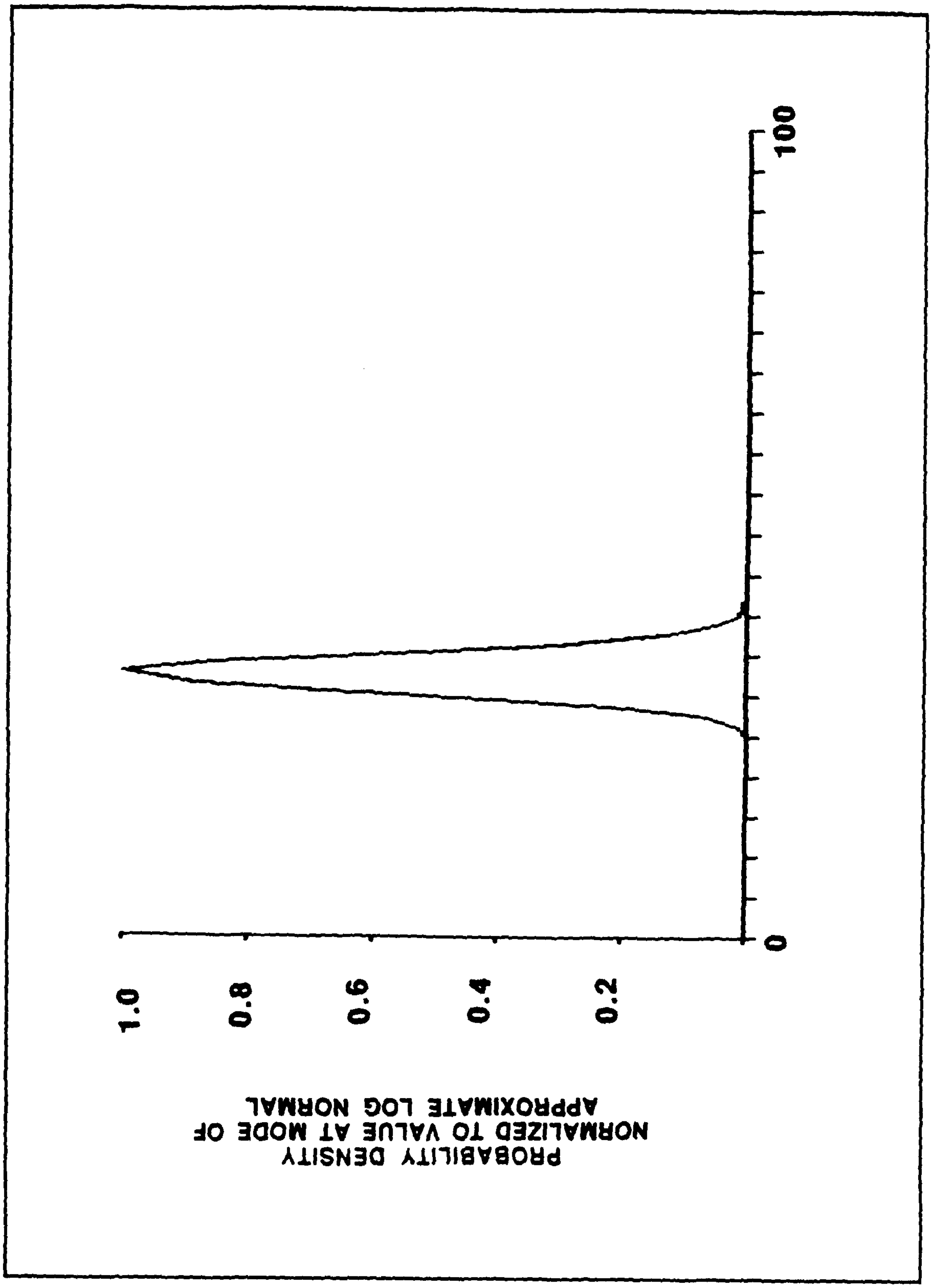

Figure A-4. Comparison of Computer Convolution and Approximation for First Example

In our case, we have only one real root, namely,

$$\exp(z) = x$$

Noting that $g'(x) = 1/x$ and that $1/|g'(x)|$ is equal to x, we have

$$f_Z(z) = x\, f_X(\exp(z))$$

$$= x \exp\left[-(1/2)\, (\ln\{\exp(z)\} - \mu)^2/\sigma^2\right] / \left[\sqrt{(2\pi)}\, \sigma x\right]$$

$$= \exp[-(1/2)(z-\mu)^2/\sigma^2] / \sqrt{(2\pi)}\sigma \qquad -\infty \le z \le \infty$$

As everyone will recognize, this is the <u>normal distribution function</u>. We also have

$$E(Z) = \mu$$
$$VAR(Z) = \sigma^2$$
$$Mode(Z) = \mu$$
$$cv = \sigma/\mu$$

It should be noted that the parameters of the transformed normal density function are readily convertible into the parameters of the log-normal density function; however, the natures of the parameters are very different from one another.

List of References

A-1. Parzen, E., Stochastic Processes, Holden-Day, San Fransicso, 1962

A-2. Papoulis, A., Probability, Random Variables, and Stochastic Processes, McGraw-Hill Book Company, New York, 1965

Appendix B

Curve Fits to Input Data

Appendix B

Curve Fits to Input Data

The following tables contain the data used in the calculations given in the report. Table B-1 presents the fitting parameters for the data taken from Figures 1 through 3 of the main body of the report. Table B-2 presents the data from Figure 1, the plot of probability versus system cost for the BSTS, and compares the curve fits for both the log-normal and the normal curve distributions. Table B-3 presents the same data for the SSTS and Table B-4 presents the same data for the SBI.

Table B-1
Curve Fit Parameters

	Log-Normal		Normal	
System	μ	σ	μ	σ
BSTS	ln(7.9)	0.12308	7.9	0.97241
SSTS	ln(8.7)	0.18352	8.7	1.5845
SBI	ln(14.33)	0.28108	14.33	3.99300

Table B-2
Curve Fit Data for BSTS

Probability	Cost	Log-Normal Cost	Normal Cost
0.00	6.59	--	--
0.10	6.89	6.75	6.60
0.20	7.16	7.12	7.08
0.30	7.40	7.41	7.39
0.40	7.64	7.66	7.66
0.50	7.88	7.90	7.90
0.60	8.15	8.15	8.14
0.70	8.42	8.42	8.41
0.80	8.90	8.76	8.72
0.90	9.35	9.25	9.14

Table B-3
Curve Fit Data for SSTS

Probability	Cost	Log-Normal Cost	Normal Cost
0.00	6.00	--	--
0.10	6.84	6.88	6.67
0.20	7.35	7.46	7.37
0.30	7.83	7.91	7.87
0.40	8.22	8.31	8.30
0.50	8.70	8.70	8.70
0.60	9.06	9.11	9.10
0.70	9.50	9.57	9.53
0.80	10.05	10.15	10.03
0.90	10.80	11.00	10.73

Table B-4
Curve Fit Data for SBI

Probability	Cost	Log-Normal Cost	Normal Cost
0.05	9.10	9.03	7.77
0.10	10.00	10.00	9.22
0.20	11.20	11.32	10.98
0.30	12.30	12.38	12.25
0.35	12.95	12.87	12.80
0.40	13.50	13.35	13.33
0.50	14.33	14.33	14.33
0.60	15.50	15.38	15.34
0.70	16.90	16.60	16.42
0.80	18.30	18.14	17.68
0.90	20.20	20.54	19.44
0.95	21.50	22.75	20.90

Appendix C

RESULTS FOR LOG-NORMAL DISTRIBUTION FITS FOR DAB ARCHITECTURE ASSUMING INPUT DATA ARE 50% CONFIDENCE VALUES

ACQUISTION COSTS FOR DAB ARCHITECTURE

System	CV	C50	R&D MU	R&D SIG	R&D EX	R&D VARX
BSTS	0.1236	5.40	1.686	0.123	5.441	0.452
SSTS	0.1851	3.80	1.335	0.184	3.865	0.512
SBI	0.2867	4.10	1.411	0.281	4.265	1.496
GSTS	0.1851	1.30	0.262	0.184	1.322	0.060
MGBR	0.1236	1.30	0.262	0.123	1.310	0.026
ERIS	0.1236	2.40	0.875	0.123	2.418	0.089
CCSOIF	0.2867	4.00	1.386	0.281	4.161	1.423
SEI	0.1236	3.70	1.308	0.123	3.728	0.212
LCH	0.1236	3.40	1.224	0.123	3.426	0.179
TOTALS		29.40			29.936	4.449
					3.399	
					ALPHA	BETA
			3.397	0.070		

ACQUISTION COSTS FOR DAB ARCHITECTURE

System	C50	INV MU	INV SIG	INV EX	INV VARX
BSTS	2.60	0.956	0.123	2.620	0.105
SSTS	5.40	1.686	0.184	5.492	1.033
SBI	13.60	2.610	0.281	14.148	16.455
GSTS	2.00	0.693	0.184	2.034	0.142
MGBR	2.00	0.693	0.123	2.015	0.062
ERIS	3.51	1.256	0.123	3.537	0.191
CCSOIF	3.30	1.194	0.281	3.433	0.969
SEI	1.30	0.262	0.123	1.310	0.026
LCH	5.20	1.649	0.123	5.240	0.419
TOTALS	38.91			39.828	19.402
				3.685	
				ALPHA	BETA
		3.678	0.110		

ACQUISTION COSTS FOR DAB ARCHITECTURE

System	TOTALS EX	VARX
BSTS	8.061	0.557
SSTS	9.356	1.545
SBI	18.413	17.951
GSTS	3.356	0.202
MGBR	3.325	0.088
ERIS	5.955	0.280
CCSOIF	7.594	2.392
SEI	5.038	0.238
LCH	8.665	0.598
TOTALS	69.764	23.851
	4.245	
	MU	4.2427
	SIG	0.0699

PROB	COSTRD	COSTINV	COSTTOT
0.1	27.29	34.38	63.64
0.2	28.15	36.09	65.63
0.3	28.79	37.37	67.10
0.4	29.34	38.50	68.38
0.5	29.86	39.59	69.59
0.6	30.39	40.70	70.83
0.7	30.98	41.93	72.18
0.8	31.68	43.42	73.80
0.9	32.68	45.59	76.11

PROGRAM COSTS FOR DAB ARCHITECTURE

			R&D			
System	CV	C50	MU	SIG	EX	VARX
BSTS	0.1236	5.40	1.686	0.123	5.441	0.452
SSTS	0.1851	3.80	1.335	0.184	3.865	0.512
SBI	0.2867	4.10	1.411	0.281	4.265	1.496
GSTS	0.1851	1.30	0.262	0.184	1.322	0.060
MGBR	0.1236	1.30	0.262	0.123	1.310	0.026
ERIS	0.1236	2.40	0.875	0.123	2.418	0.089
TGBR	0.1236	1.10	0.095	0.123	1.108	0.019
HEDI	0.1236	1.50	0.405	0.123	1.511	0.035
CCSOIF	0.2867	4.25	1.447	0.281	4.421	1.607
SEI	0.1236	4.11	1.413	0.123	4.141	0.262
LCH	0.1236	3.40	1.224	0.123	3.426	0.179
TOTALS		32.66			33.229	4.736
					3.503	
					ALPHA	BETA
			3.501	0.065		

PROGRAM COSTS FOR DAB ARCHITECTURE

			INV		
System	C50	MU	SIG	EX	VARX
BSTS	2.60	0.956	0.123	2.620	0.105
SSTS	5.40	1.686	0.184	5.492	1.033
SBI	13.60	2.610	0.281	14.148	16.455
GSTS	2.00	0.693	0.184	2.034	0.142
MGBR	2.00	0.693	0.123	2.015	0.062
ERIS	3.51	1.256	0.123	3.537	0.191
TGBR	0.00	0.000	0.000	0.000	0.000
HEDI	0.00	0.000	0.000	0.000	0.000
CCSOIF	3.32	1.200	0.281	3.454	0.981
SEI	1.30	0.262	0.123	1.310	0.026
LCH	5.20	1.649	0.123	5.240	0.419

PROGRAM COSTS FOR DAB ARCHITECTURE

System	TOTALS EX	TOTALS VARX
BSTS	8.061	0.557
SSTS	9.356	1.545
SBI	18.413	17.951
GSTS	3.356	0.202
MGBR	3.325	0.088
ERIS	5.955	0.280
TGBR	1.108	0.019
HEDI	1.511	0.035
CCSOIF	7.875	2.588
SEI	5.451	0.288
LCH	8.665	0.598
TOTALS	73.078	24.149
	4.292	
	MU	4.2893
	SIG	0.0672

PROB	COSTRD	COSTINV	COSTTOT
0.1	30.49	34.39	66.91
0.2	31.39	36.11	68.92
0.3	32.05	37.39	70.40
0.4	32.62	38.52	71.69
0.5	33.16	39.61	72.91
0.6	33.71	40.72	74.15
0.7	34.31	41.95	75.51
0.8	35.03	43.45	77.14
0.9	36.05	45.61	79.46

Appendix D

RESULTS FOR LOG-NORMAL DISTRIBUTION FITS FOR DAB ARCHITECTURE ASSUMING INPUT DATA ARE EXPECTED VALUES

ACQUISTION COSTS FOR DAB ARCHITECTURE

System	CV	E(X)	R&D MU	R&D SIG	R&D EX	R&D VARX
BSTS	0.1236	5.40	1.679	0.123	5.400	0.445
SSTS	0.1851	3.80	1.318	0.184	3.799	0.494
SBI	0.2867	4.10	1.370	0.281	4.093	1.378
GSTS	0.1851	1.30	0.245	0.184	1.300	0.058
MGBR	0.1236	1.30	0.255	0.123	1.300	0.026
ERIS	0.1236	2.40	0.868	0.123	2.400	0.088
CCSOIF	0.2867	4.00	1.345	0.281	3.994	1.311
SEI	0.1236	3.70	1.301	0.123	3.700	0.209
LCH	0.1236	3.40	1.216	0.123	3.400	0.176
TOTALS		29.40			29.385	4.185
					3.380	
					ALPHA	BETA
			3.378	0.070		

ACQUISTION COSTS FOR DAB ARCHITECTURE

System	EX	INV MU	INV SIG	INV EX	INV VARX
BSTS	2.60	0.948	0.123	2.600	0.103
SSTS	5.40	1.670	0.184	5.400	0.999
SBI	13.60	2.571	0.281	13.600	15.205
GSTS	2.00	0.676	0.184	2.000	0.137
MGBR	2.00	0.686	0.123	2.000	0.061
ERIS	3.51	1.248	0.123	3.510	0.188
CCSOIF	3.30	1.154	0.281	3.300	0.895
SEI	1.30	0.255	0.123	1.300	0.026
LCH	5.20	1.641	0.123	5.200	0.413
TOTALS	38.91			38.910	18.027
				3.661	
				ALPHA	BETA
		3.655	0.109		

ACQUISTION COSTS FOR DAB ARCHITECTURE

System	TOTALS EX	VARX
BSTS	8.000	0.548
SSTS	9.199	1.493
SBI	17.693	16.583
GSTS	3.300	0.195
MGBR	3.300	0.087
ERIS	5.910	0.276
CCSOIF	7.294	2.206
SEI	5.000	0.235
LCH	8.600	0.589
TOTALS	68.295	22.212
	4.224	
	MU	4.2215
	SIG	0.0689

PROB	COSTRD	COSTINV	COSTTOT
0.1	26.82	33.65	62.38
0.2	27.65	35.31	64.30
0.3	28.27	36.55	65.73
0.4	28.81	37.64	66.96
0.5	29.31	38.68	68.13
0.6	29.83	39.75	69.32
0.7	30.40	40.94	70.63
0.8	31.07	42.38	72.19
0.9	32.04	44.46	74.42

PROGRAM COSTS FOR DAB ARCHITECTURE

System	CV	EX	R&D MU	R&D SIG	R&D EX	R&D VARX
BSTS	0.1236	5.40	1.679	0.123	5.400	0.445
SSTS	0.1851	3.80	1.318	0.184	3.800	0.495
SBI	0.2867	4.10	1.371	0.281	4.100	1.382
GSTS	0.1851	1.30	0.246	0.184	1.300	0.058
MGBR	0.1236	1.30	0.255	0.123	1.300	0.026
ERIS	0.1236	2.40	0.868	0.123	2.400	0.088
TGBR	0.1236	1.10	0.088	0.123	1.100	0.018
HEDI	0.1236	1.50	0.398	0.123	1.500	0.034
CCSOIF	0.2867	4.25	1.407	0.281	4.250	1.485
SEI	0.1236	4.11	1.406	0.123	4.110	0.258
LCH	0.1236	3.40	1.216	0.123	3.400	0.176
TOTALS		32.66			32.660	4.465
					3.486	
					ALPHA	BETA
			3.484	0.065		

PROGRAM COPROGRAM COSTS FOR DAB ARCHITECTURE

System	EX	INV MU	INV SIG	INV EX	INV VARX
BSTS	2.60	0.948	0.123	2.600	0.103
SSTS	5.40	1.670	0.184	5.400	0.999
SBI	13.60	2.571	0.281	13.600	15.205
GSTS	2.00	0.676	0.184	2.000	0.137
MGBR	1.80	0.580	0.123	1.800	0.049
ERIS	3.51	1.248	0.123	3.510	0.188
TGBR	0.00	0.000	0.000	0.000	0.000
HEDI	0.00	0.000	0.000	0.000	0.000
CCSOIF	3.32	1.160	0.281	3.320	0.906
SEI	1.30	0.255	0.123	1.300	0.026
LCH	5.20	1.641	0.123	5.200	0.413
TOTALS	38.73			38.730	18.027
				3.657	
				ALPHA	BETA
		3.651	0.109		

PROGRAM COSTS FOR DAB ARCHITECTURE

System	TOTALS EX	VARX
BSTS	8.000	0.548
SSTS	9.200	1.494
SBI	17.700	16.587
GSTS	3.300	0.195
MGBR	3.100	0.075
ERIS	5.910	0.276
TGBR	1.100	0.018
HEDI	1.500	0.034
CCSOIF	7.570	2.391
SEI	5.410	0.284
LCH	8.600	0.589
TOTALS	71.390	22.492
	4.268	
	MU	4.2660
	SIG	0.0664

PROB	COSTRD	COSTINV	COSTTOT
0.1	30.00	33.47	65.43
0.2	30.87	35.13	67.38
0.3	31.51	36.37	68.81
0.4	32.07	37.46	70.05
0.5	32.59	38.50	71.23
0.6	33.13	39.57	72.43
0.7	33.71	40.76	73.74
0.8	34.41	42.20	75.31
0.9	35.40	44.28	77.55

Appendix E

RESULTS FOR NORMAL DISTRIBUTION FITS FOR DAB ARCHITECTURE ASSUMING INPUT DATA ARE EXPECTED VALUES

ACQUISTION COSTS FOR DAB ARCHITECTURE

System	CV	C50	EX	VARX
BSTS	0.1231	5.40	5.400	0.442
SSTS	0.1821	3.80	3.800	0.479
SBI	0.2786	4.10	4.100	1.305
GSTS	0.1821	1.30	1.300	0.056
MGBR	0.1231	1.30	1.300	0.026
ERIS	0.1231	2.40	2.400	0.087
CCSOIF	0.2786	4.00	4.000	1.242
SEI	0.1231	3.70	3.700	0.207
LCH	0.1231	3.40	3.400	0.175
TOTALS		29.40	29.400	2.005

ACQUISTION COSTS FOR DAB ARCHITECTURE

System	C50	EX	VARX
BSTS	2.60	2.600	0.102
SSTS	5.40	5.400	0.967
SBI	13.60	13.600	14.356
GSTS	2.00	2.000	0.133
MGBR	2.00	2.000	0.061
ERIS	3.51	3.510	0.187
CCSOIF	3.30	3.300	0.845
SEI	1.30	1.300	0.026
LCH	5.20	5.200	0.410
TOTALS	38.91	38.910	4.134

ACQUISTION COSTS FOR DAB ARCHITECTURE

System	EX	VARX
	TOTALS	
BSTS	8.000	0.544
SSTS	9.200	1.446
SBI	17.700	15.661
GSTS	3.300	0.189
MGBR	3.300	0.086
ERIS	5.910	0.274
CCSOIF	7.300	2.087
SEI	5.000	0.233
LCH	8.600	0.585
TOTALS	68.310	4.594
	MU	68.3100
	SIG	4.5940

PROB	COSTRD	COSTINV	COSTTOT
0.1	26.83	33.62	62.43
0.2	27.72	35.44	64.46
0.3	28.35	36.75	65.91
0.4	28.90	37.87	67.16
0.5	29.40	38.91	68.31
0.6	29.90	39.95	69.46
0.7	30.45	41.07	70.71
0.8	31.08	42.38	72.16
0.9	31.97	44.20	74.19

PROGRAM COSTS FOR DAB ARCHITECTURE

System	CV	C50	EX	VARX
BSTS	0.1231	5.40	5.400	0.442
SSTS	0.1821	3.80	3.800	0.479
SBI	0.2786	4.10	4.100	1.305
GSTS	0.1821	1.30	1.300	0.056
MGBR	0.1231	1.30	1.300	0.026
ERIS	0.1231	2.40	2.400	0.087
TGBR	0.1231	1.10	1.100	0.018
HEDI	0.1231	1.50	1.500	0.034
CCSOIF	0.2786	4.25	4.250	1.402
SEI	0.1231	4.11	4.110	0.256
LCH	0.1231	3.40	3.400	0.175
TOTALS		32.66	32.660	2.069

PROGRAM COPROGRAM COSTS FOR DAB ARCHIT

System	C50	EX	VARX
BSTS	2.60	2.600	0.102
SSTS	5.40	5.400	0.967
SBI	13.60	13.600	14.356
GSTS	2.00	2.000	0.133
MGBR	2.00	2.000	0.061
ERIS	3.51	3.510	0.187
TGBR	0.00	0.000	0.000
HEDI	0.00	0.000	0.000
CCSOIF	3.32	3.320	0.856
SEI	1.30	1.300	0.026
LCH	5.20	5.200	0.410
TOTALS	38.93	38.930	4.135

PROGRAM COSTS FOR DAB ARCHITECTURE

System	TOTALS EX	VARX
BSTS	8.000	0.544
SSTS	9.200	1.446
SBI	17.700	15.661
GSTS	3.300	0.189
MGBR	3.300	0.086
ERIS	5.910	0.274
TGBR	1.100	0.018
HEDI	1.500	0.034
CCSOIF	7.570	2.258
SEI	5.410	0.282
LCH	8.600	0.585
TOTALS	71.590	4.623
	MU	71.5900
	SIG	4.6235

PROB	COSTRD	COSTINV	COSTTOT
0.1	30.01	33.64	65.67
0.2	30.92	35.46	67.71
0.3	31.58	36.77	69.18
0.4	32.14	37.89	70.43
0.5	32.66	38.93	71.59
0.6	33.18	39.97	72.75
0.7	33.74	41.09	74.00
0.8	34.40	42.40	75.47
0.9	35.31	44.22	77.51

Appendix F

SENSITIVITY TO RISK SPLIT BETWEEN PHASES FOR DAB ARCHITECTURE FOR NORMAL DISTRIBUTION FITS

ACQUISTION COSTS FOR DAB ARCHITECTURE

System	CV	C50	EX	VARX
BSTS	0.1231	5.40	5.400	0.945
SSTS	0.1821	3.80	3.800	2.292
SBI	0.2786	4.10	4.100	10.941
GSTS	0.1821	1.30	1.300	0.286
MGBR	0.1231	1.30	1.300	0.131
ERIS	0.1231	2.40	2.400	0.428
CCSOIF	0.2786	4.00	4.000	3.845
SEI	0.1231	3.70	3.700	0.374
LCH	0.1231	3.40	3.400	0.890
TOTALS		29.40	29.400	4.487

ACQUISTION COSTS FOR DAB ARCHITECTURE

System	C50	EX	VARX
BSTS	2.60	2.600	0.024
SSTS	5.40	5.400	0.514
SBI	13.60	13.600	13.376
GSTS	2.00	2.000	0.075
MGBR	2.00	2.000	0.034
ERIS	3.51	3.510	0.102
CCSOIF	3.30	3.300	0.291
SEI	1.30	1.300	0.005
LCH	5.20	5.200	0.231
TOTALS	38.91	38.910	3.828

ACQUISTION COSTS FOR DAB ARCHITECTURE

System	TOTALS EX	TOTALS VARX
BSTS	8.000	0.970
SSTS	9.200	2.807
SBI	17.700	24.317
GSTS	3.300	0.361
MGBR	3.300	0.165
ERIS	5.910	0.529
CCSOIF	7.300	4.136
SEI	5.000	0.379
LCH	8.600	1.121
TOTALS	68.310	5.898
	MU	68.3100
	SIG	5.8979

PROB	COSTRD	COSTINV	COSTTOT
0.1	23.66	34.01	60.76
0.2	25.64	35.70	63.36
0.3	27.06	36.91	65.23
0.4	28.27	37.95	66.83
0.5	29.40	38.91	68.31
0.6	30.53	39.87	69.79
0.7	31.74	40.91	71.39
0.8	33.16	42.12	73.26
0.9	35.14	43.81	75.86

PROGRAM COSTS FOR DAB ARCHITECTURE

System	CV	C50	EX	VARX
BSTS	0.1231	5.40	5.400	0.945
SSTS	0.1821	3.80	3.800	2.292
SBI	0.2786	4.10	4.100	10.941
GSTS	0.1821	1.30	1.300	0.286
MGBR	0.1231	1.30	1.300	0.131
ERIS	0.1231	2.40	2.400	0.428
TGBR	0.1231	1.10	1.100	0.131
HEDI	0.1231	1.50	1.500	0.428
CCSOIF	0.2786	4.25	4.250	4.165
SEI	0.1231	4.11	4.110	0.439
LCH	0.1231	3.40	3.400	0.890
TOTALS		32.66	32.660	4.591

PROGRAM COSTS FOR DAB ARCHITECTURE

System	C50	EX	VARX
BSTS	2.60	2.600	0.024
SSTS	5.40	5.400	0.514
SBI	13.60	13.600	13.376
GSTS	2.00	2.000	0.075
MGBR	2.00	2.000	0.034
ERIS	3.51	3.510	0.102
TGBR	0.00	0.000	0.000
HEDI	0.00	0.000	0.000
CCSOIF	3.32	3.320	0.282
SEI	1.30	1.300	0.005
LCH	5.20	5.200	0.231
TOTALS	38.93	38.930	3.827

PROGRAM COSTS FOR DAB ARCHITECTURE

System	TOTALS EX	TOTALS VARX
BSTS	8.000	0.970
SSTS	9.200	2.807
SBI	17.700	24.317
GSTS	3.300	0.361
MGBR	3.300	0.165
ERIS	5.910	0.529
TGBR	1.100	0.131
HEDI	1.500	0.428
CCSOIF	7.570	4.448
SEI	5.410	0.444
LCH	8.600	1.121
TOTALS	71.590	5.977
	MU	71.5900
	SIG	5.9766

PROB	COSTRD	COSTINV	COSTTOT
0.1	26.78	34.03	63.94
0.2	28.81	35.72	66.58
0.3	30.27	36.93	68.47
0.4	31.51	37.97	70.09
0.5	32.66	38.93	71.59
0.6	33.81	39.89	73.09
0.7	35.05	40.93	74.71
0.8	36.51	42.14	76.60
0.9	38.54	43.83	79.24

Appendix G

RESULTS FOR CORRELATED NORMAL DISTRIBUTION FITS FOR ALL ARCHITECTURES

ACQUISITION COSTS FOR DAB ARCHITECTURE

		R&D		
System	CV	C50	EX	VARX
BSTS	0.1231	5.40	5.400	0.442
SSTS	0.1821	3.80	3.800	0.479
SBI	0.2786	4.10	4.100	1.305
GSTS	0.1821	1.30	1.300	0.056
MGBR	0.1231	1.30	1.300	0.026
ERIS	0.1231	2.40	2.400	0.087
CCSOIF	0.2786	4.00	4.000	1.242
SEI	0.1231	3.70	3.700	0.207
LCH	0.1231	3.40	3.400	0.175
TOTALS		29.40	29.400	2.005
			MUR&D	SIGR&D

ACQUISITION COSTS FOR DAB ARCHITECTURE

	INV		
System	C50	EX	VARX
BSTS	2.60	2.600	0.102
SSTS	5.40	5.400	0.967
SBI	13.60	13.600	14.356
GSTS	2.00	2.000	0.133
MGBR	2.00	2.000	0.061
ERIS	3.51	3.510	0.187
CCSOIF	3.30	3.300	0.845
SEI	1.30	1.300	0.026
LCH	5.20	5.200	0.410
TOTALS	38.91	38.910	4.134
		MUINV	SIGINV

ACQUISITION COSTS FOR DAB ARCHITECTURE

System	TOTALS EX	TOTALS VARX
BSTS	8.000	0.757
SSTS	9.200	2.126
SBI	17.700	19.989
GSTS	3.300	0.275
MGBR	3.300	0.126
ERIS	5.910	0.402
CCSOIF	7.300	3.112
SEI	5.000	0.306
LCH	8.600	0.853
TOTALS	68.310	5.286
	MU	SIG
	MU	68.3100
	SIG	8.5294

Correlation between Phases 0.50

PROB	COSTRD	COSTINV	COSTTOT
0.1	26.83	33.62	57.39
0.2	27.72	35.44	61.15
0.3	28.35	36.75	63.86
0.4	28.90	37.87	66.17
0.5	29.40	38.91	68.31
0.6	29.90	39.95	70.45
0.7	30.45	41.07	72.76
0.8	31.08	42.38	75.47
0.9	31.97	44.20	79.23

PROGRAM COSTS FOR DAB ARCHITECTURE

System	CV	C50	R&D EX	R&D VARX
BSTS	0.1231	5.40	5.400	0.442
SSTS	0.1821	3.80	3.800	0.479
SBI	0.2786	4.10	4.100	1.305
GSTS	0.1821	1.30	1.300	0.056
MGBR	0.1231	1.30	1.300	0.026
ERIS	0.1231	2.40	2.400	0.087
TGBR	0.1231	1.10	1.100	0.018
HEDI	0.1231	1.50	1.500	0.034
CCSOIF	0.2786	4.25	4.250	1.402
SEI	0.1231	4.11	4.110	0.256
LCH	0.1231	3.40	3.400	0.175
TOTALS		32.66	32.660	2.069
			MUR&D	SIGR&D

PROGRAM COSTS FOR DAB ARCHITECTURE

System	INV C50	INV EX	INV VARX
BSTS	2.60	2.600	0.102
SSTS	5.40	5.400	0.967
SBI	13.60	13.600	14.356
GSTS	2.00	2.000	0.133
MGBR	2.00	2.000	0.061
ERIS	3.51	3.510	0.187
TGBR	0.00	0.000	0.000
HEDI	0.00	0.000	0.000
CCSOIF	3.32	3.320	0.856
SEI	1.30	1.300	0.026
LCH	5.20	5.200	0.410
TOTALS	38.93	38.930	4.135
		MUINV	SIGINV

PROGRAM COSTS FOR DAB ARCHITECTURE

System	TOTALS EX	VARX
BSTS	8.000	0.757
SSTS	9.200	2.126
SBI	17.700	19.989
GSTS	3.300	0.275
MGBR	3.300	0.126
ERIS	5.910	0.402
TGBR	1.100	0.018
HEDI	1.500	0.034
CCSOIF	7.570	3.353
SEI	5.410	0.363
LCH	8.600	0.853
TOTALS	71.590	5.319
	MU	SIG
	MU	71.5900
	SIG	9.2740

PROB	COSTRD	COSTINV	COSTTOT
0.1	30.01	33.64	59.72
0.2	30.92	35.46	63.81
0.3	31.58	36.77	66.75
0.4	32.14	37.89	69.26
0.5	32.66	38.93	71.59
0.6	33.18	39.97	73.92
0.7	33.74	41.09	76.43
0.8	34.40	42.40	79.37
0.9	35.31	44.22	83.46

Correlation Between Phases 0.50

Correlation Between Programs	---- Acquisition Costs 20%	50%	80% -----------	Program Costs 20%	50%	80% -----
0.0	63.87	68.31	72.75	67.13	71.59	76.05
0.1	63.21	68.31	73.41	66.29	71.59	76.89
0.2	62.63	68.31	73.99	65.58	71.59	77.60
0.3	62.10	68.31	74.52	64.93	71.59	78.25
0.4	61.61	68.31	75.01	64.35	71.59	78.83
0.5	61.15	68.31	75.47	63.81	71.59	79.37
0.6	60.73	68.31	75.89	63.30	71.59	79.88
0.7	60.32	68.31	76.30	62.83	71.59	80.35
0.8	59.93	68.31	76.69	62.37	71.59	80.81
0.9	59.57	68.31	77.05	61.94	71.59	81.24
1.0	59.21	68.31	77.41	61.53	71.59	81.65

ACQUISITION COSTS FOR ERIS ARCHITECTURE

System	CV	R&D C50	R&D EX	R&D VARX
BSTS	0.1231	5.40	5.400	0.442
SSTS	0.1821	3.80	3.800	0.479
GSTS	0.1821	1.30	1.300	0.056
MGBR	0.1231	1.30	1.300	0.026
ERIS	0.1231	2.40	2.400	0.087
CCSOIF	0.2786	3.98	3.980	1.229
SEI	0.1231	2.81	2.810	0.120
LCH	0.1231	1.30	1.300	0.026
TOTALS		22.29	22.290	1.570
			MUR&D	SIGR&D

ACQUISITION COSTS FOR ERIS ARCHITECTUR

System	INV C50	INV EX	INV VARX
BSTS	2.60	2.600	0.102
SSTS	4.32	4.320	0.619
GSTS	2.75	2.750	0.251
MGBR	2.00	2.000	0.061
ERIS	6.02	6.020	0.549
CCSOIF	3.90	3.900	1.181
SEI	0.82	0.820	0.010
LCH	1.60	1.600	0.039
TOTALS	24.01	24.010	1.677
		MUINV	SIGINV

ACQUISITION COSTS FOR ERIS ARCHITECTURE

System	TOTALS EX	TOTALS VARX
BSTS	8.000	0.757
SSTS	8.120	1.642
GSTS	4.050	0.425
MGBR	3.300	0.126
ERIS	8.420	0.855
CCSOIF	7.880	3.615
SEI	3.630	0.165
LCH	2.900	0.096
TOTALS	46.300	2.771
	MU	SIG
	MU	46.3000
	SIG	5.0295

Correlation between Phases 0.50

PROB	COSTRD	COSTINV	COSTTOT
0.1	20.28	21.86	39.86
0.2	20.97	22.60	42.08
0.3	21.47	23.14	43.68
0.4	21.90	23.59	45.04
0.5	22.29	24.01	46.30
0.6	22.68	24.43	47.56
0.7	23.11	24.88	48.92
0.8	23.61	25.42	50.52
0.9	24.30	26.16	52.74

PROGRAM COSTS FOR ERIS ARCHITECTURE

		R&D		
System	CV	C50	EX	VARX
BSTS	0.1231	5.40	5.400	0.442
SSTS	0.1821	3.80	3.800	0.479
SBI	0.2786	4.10	4.100	1.305
GSTS	0.1821	1.30	1.300	0.056
MGBR	0.1231	1.30	1.300	0.026
ERIS	0.1231	2.40	2.400	0.087
TGBR	0.1231	1.10	1.100	0.018
HEDI	0.1231	1.50	1.500	0.034
CCSOIF	0.2786	4.25	4.250	1.402
SEI	0.1231	4.11	4.110	0.256
LCH	0.1231	3.40	3.400	0.175
TOTALS		32.66	32.660	2.069
			MUR&D	SIGR&D

PROGRAM COSTS FOR ERIS ARCHITECTURE

	INV		
System	C50	EX	VARX
BSTS	2.60	2.600	0.102
SSTS	4.32	4.320	0.619
SBI	0.00	0.000	0.000
GSTS	2.75	2.750	0.251
MGBR	2.00	2.000	0.061
ERIS	6.02	6.020	0.549
TGBR	0.00	0.000	0.000
HEDI	0.00	0.000	0.000
CCSOIF	3.90	3.900	1.181
SEI	0.82	0.820	0.010
LCH	1.60	1.600	0.039
TOTALS	24.01	24.010	1.677
		MUINV	SIGINV

PROGRAM COSTS FOR ERIS ARCHITECTURE

System	TOTALS	
	EX	VARX
BSTS	8.000	0.757
SSTS	8.120	1.642
SBI	4.100	1.305
GSTS	4.050	0.425
MGBR	3.300	0.126
ERIS	8.420	0.855
TGBR	1.100	0.018
HEDI	1.500	0.034
CCSOIF	8.150	3.869
SEI	4.930	0.317
LCH	5.000	0.296
TOTALS	56.670	3.106
	MU	SIG
	MU	56.6700
	SIG	6.4788

PROB	COSTRD	COSTINV	COSTTOT
0.1	30.01	21.86	48.38
0.2	30.92	22.60	51.23
0.3	31.58	23.14	53.29
0.4	32.14	23.59	55.04
0.5	32.66	24.01	56.67
0.6	33.18	24.43	58.30
0.7	33.74	24.88	60.05
0.8	34.40	25.42	62.11
0.9	35.31	26.16	64.96

Correlation Between Phases 0.50

Correlation Between Programs	---- Acquisition Costs 20%	50%	80% -----------	Program Costs 20%	50%	80% -----
0.0	43.97	46.3	48.63	54.06	56.67	59.28
0.1	43.49	46.3	49.11	53.30	56.67	60.04
0.2	43.08	46.3	49.52	52.68	56.67	60.66
0.3	42.72	46.3	49.88	52.15	56.67	61.19
0.4	42.38	46.3	50.22	51.67	56.67	61.67
0.5	42.08	46.3	50.52	51.23	56.67	62.11
0.6	41.80	46.3	50.80	50.83	56.67	62.51
0.7	41.53	46.3	51.07	50.45	56.67	62.89
0.8	41.27	46.3	51.33	50.10	56.67	63.24
0.9	41.03	46.3	51.57	49.76	56.67	63.58
1.0	40.80	46.3	51.80	49.44	56.67	63.90

ACQUISITION COSTS FOR ERIS/HEDI ARCHITECTURE

System	CV	R&D C50	R&D EX	R&D VARX
BSTS	0.1231	5.40	5.400	0.442
SSTS	0.1821	3.80	3.800	0.479
GSTS	0.1821	1.30	1.300	0.056
MGBR	0.1231	1.30	1.300	0.026
ERIS	0.1231	2.40	2.400	0.087
TGBR	0.1231	1.10	1.100	0.018
HEDI	0.1231	1.50	1.500	0.034
CCSOIF	0.2786	4.23	4.230	1.389
SEI	0.1231	3.22	3.220	0.157
LCH	0.1231	1.30	1.300	0.026
TOTALS		25.55	25.550 MUR&D	1.647 SIGR&D

ACQUISITION COSTS FOR ERIS/HEDI ARCHIT

System	INV C50	INV EX	INV VARX
BSTS	2.60	2.600	0.102
SSTS	4.32	4.320	0.619
GSTS	2.75	2.750	0.251
MGBR	2.00	2.000	0.061
ERIS	5.08	5.080	0.391
TGBR	6.16	6.160	0.575
HEDI	5.86	5.860	0.520
CCSOIF	5.93	5.930	2.729
SEI	1.26	1.260	0.024
LCH	1.60	1.600	0.039
TOTALS	37.56	37.560 MUINV	2.305 SIGINV

ACQUISITION COSTS FOR ERIS/HEDI ARCHITECTURE

Correlation between Phases 0.50

System	TOTALS EX	TOTALS VARX
BSTS	8.000	0.757
SSTS	8.120	1.642
GSTS	4.050	0.425
MGBR	3.300	0.126
ERIS	7.480	0.663
TGBR	7.260	0.696
HEDI	7.360	0.688
CCSOIF	10.160	6.065
SEI	4.480	0.243
LCH	2.900	0.096
TOTALS	63.110	3.376
	MU	SIG
	MU	63.1100
	SIG	5.7460

PROB	COSTRD	COSTINV	COSTTOT
0.1	23.44	34.61	55.75
0.2	24.17	35.63	58.29
0.3	24.69	36.36	60.11
0.4	25.14	36.98	61.67
0.5	25.55	37.56	63.11
0.6	25.96	38.14	64.55
0.7	26.41	38.76	66.11
0.8	26.93	39.49	67.93
0.9	27.66	40.51	70.47

PROGRAM COSTS FOR ERIS/HEDI ARCHITECTURE

System	CV	C50	R&D EX	R&D VARX
BSTS	0.1231	5.40	5.400	0.442
SSTS	0.1821	3.80	3.800	0.479
SBI	0.2786	4.10	4.100	1.305
GSTS	0.1821	1.30	1.300	0.056
MGBR	0.1231	1.30	1.300	0.026
ERIS	0.1231	2.40	2.400	0.087
TGBR	0.1231	1.10	1.100	0.018
HEDI	0.1231	1.50	1.500	0.034
CCSOIF	0.2786	4.25	4.250	1.402
SEI	0.1231	4.11	4.110	0.256
LCH	0.1231	3.40	3.400	0.175
TOTALS		32.66	32.660 MUR&D	2.069 SIGR&D

PROGRAM COSTS FOR ERIS/HEDI ARCHITECTU

System	C50	INV EX	INV VARX
BSTS	2.60	2.600	0.102
SSTS	4.32	4.320	0.619
SBI	0.00	0.000	0.000
GSTS	2.75	2.750	0.251
MGBR	2.00	2.000	0.061
ERIS	5.08	5.080	0.391
TGBR	6.16	6.160	0.575
HEDI	5.86	5.860	0.520
CCSOIF	5.93	5.930	2.729
SEI	1.26	1.260	0.024
LCH	1.60	1.600	0.039
TOTALS	37.56	37.560 MUINV	2.305 SIGINV

PROGRAM COSTS FOR ERIS/HEDI ARCHITECTURE

System	TOTALS EX	VARX
BSTS	8.000	0.757
SSTS	8.120	1.642
SBI	4.100	1.305
GSTS	4.050	0.425
MGBR	3.300	0.126
ERIS	7.480	0.663
TGBR	7.260	0.696
HEDI	7.360	0.688
CCSOIF	10.180	6.088
SEI	5.370	0.359
LCH	5.000	0.296
TOTALS	70.220	3.612
	MU	SIG
	MU	70.2200
	SIG	7.7772

PROB	COSTRD	COSTINV	COSTTOT
0.1	30.01	34.61	60.26
0.2	30.92	35.63	63.69
0.3	31.58	36.36	66.16
0.4	32.14	36.98	68.27
0.5	32.66	37.56	70.22
0.6	33.18	38.14	72.17
0.7	33.74	38.76	74.28
0.8	34.40	39.49	76.75
0.9	35.31	40.51	80.18

Correlation Between Phases 0.50

Correlation Between Programs	---- Acquisition Costs		-----------	Program Costs -----		
	20%	50%	80%	20%	50%	80%
0.0	60.29	63.11	65.93	67.19	70.22	73.25
0.1	59.79	63.11	66.43	66.24	70.22	74.20
0.2	59.36	63.11	66.86	65.47	70.22	74.97
0.3	58.97	63.11	67.25	64.81	70.22	75.63
0.4	58.62	63.11	67.60	64.23	70.22	76.21
0.5	58.29	63.11	67.93	63.69	70.22	76.75
0.6	57.98	63.11	68.24	63.20	70.22	77.24
0.7	57.69	63.11	68.53	62.74	70.22	77.70
0.8	57.42	63.11	68.80	62.31	70.22	78.13
0.9	57.15	63.11	69.07	61.89	70.22	78.55
1.0	56.90	63.11	69.32	61.50	70.22	78.94

ACQUISITION COSTS FOR BP ARCHITECTURE

System	CV	C50	R&D EX	R&D VARX
BSTS	0.1231	5.40	5.400	0.442
SSTS	0.1821	3.80	3.800	0.479
SBI	0.2786	3.50	3.500	0.951
CCSOIF	0.2786	3.52	3.520	0.962
SEI	0.1231	2.83	2.830	0.121
LCH	0.1231	3.40	3.400	0.175
TOTALS		22.45	22.450 MUR&D	1.769 SIGR&D

ACQUISITION COSTS FOR BP ARCHITECTURE

System	C50	INV EX	INV VARX
BSTS	2.60	2.600	0.102
SSTS	4.32	4.320	0.619
SBI	1.10	1.100	0.094
CCSOIF	1.97	1.970	0.301
SEI	0.55	0.550	0.005
LCH	4.91	4.910	0.365
TOTALS	15.45	15.450 MUINV	1.219 SIGINV

ACQUISITION COSTS FOR BP ARCHITECTURE

Correlation between Phases 0.50

System	TOTALS EX	TOTALS VARX
BSTS	8.000	0.757
SSTS	8.120	1.642
SBI	4.600	1.344
CCSOIF	5.490	1.801
SEI	3.380	0.150
LCH	8.310	0.793
TOTALS	37.900	2.547
	MU	SIG
	MU	37.9000
	SIG	4.5637

PROB	COSTRD	COSTINV	COSTTOT
0.1	20.19	13.89	32.06
0.2	20.97	14.43	34.07
0.3	21.53	14.81	35.52
0.4	22.01	15.14	36.75
0.5	22.45	15.45	37.90
0.6	22.89	15.76	39.05
0.7	23.37	16.09	40.28
0.8	23.93	16.47	41.73
0.9	24.71	17.01	43.74

PROGRAM COSTS FOR BP ARCHITECTURE

System	CV	R&D C50	R&D EX	R&D VARX
BSTS	0.1231	5.40	5.400	0.442
SSTS	0.1821	3.80	3.800	0.479
SBI	0.2786	3.50	3.500	0.951
GSTS	0.1821	1.30	1.300	0.056
MGBR	0.1231	1.30	1.[illegible]00	0.026
ERIS	0.1231	2.40	2.400	0.087
TGBR	0.1231	1.10	1.100	0.018
HEDI	0.1231	1.50	1.500	0.034
CCSOIF	0.2786	4.25	4.250	1.402
SEI	0.1231	4.11	4.110	0.256
LCH	0.1231	3.40	3.400	0.175
TOTALS		32.06	32.060	1.981
			MUR&D	SIGR&D

PROGRAM COSTS FOR BP ARCHITECTURE

System	INV C50	INV EX	INV VARX
BSTS	2.60	2.600	0.102
SSTS	4.32	4.320	0.619
SBI	1.10	1.100	0.094
GSTS	0.00	0.000	0.000
MGBR	0.00	0.000	0.000
ERIS	0.00	0.000	0.000
TGBR	0.00	0.000	0.000
HEDI	0.00	0.000	0.000
CCSOIF	1.97	1.970	0.301
SEI	0.55	0.550	0.005
LCH	4.91	4.910	0.365
TOTALS	15.45	15.450	1.219
		MUINV	SIGINV

PROGRAM COSTS FOR BP ARCHITECTURE

System	TOTALS EX	VARX
BSTS	8.000	0.757
SSTS	8.120	1.642
SBI	4.600	1.344
GSTS	1.300	0.056
MGBR	1.300	0.026
ERIS	2.400	0.087
TGBR	1.100	0.018
HEDI	1.500	0.034
CCSOIF	6.220	2.353
SEI	4.660	0.295
LCH	8.310	0.793
TOTALS	47.510	2.721
	MU	SIG
	MU	47.5100
	SIG	5.5027

PROB	COSTRD	COSTINV	COSTTOT
0.1	29.52	13.89	40.47
0.2	30.40	14.43	42.89
0.3	31.03	14.81	44.64
0.4	31.56	15.14	46.13
0.5	32.06	15.45	47.51
0.6	32.56	15.76	48.89
0.7	33.09	16.09	50.38
0.8	33.72	16.47	52.13
0.9	34.60	17.01	54.55

Correlation Between Phases 0.50

Correlation Between Programs	---- Acquisition Costs		-----------	Program Costs -----		
	20%	50%	80%	20%	50%	80%
0.0	35.76	37.9	40.04	45.23	47.51	49.79
0.1	35.33	37.9	40.47	44.61	47.51	50.41
0.2	34.97	37.9	40.83	44.10	47.51	50.92
0.3	34.64	37.9	41.16	43.65	47.51	51.37
0.4	34.34	37.9	41.46	43.26	47.51	51.76
0.5	34.07	37.9	41.73	42.89	47.51	52.13
0.6	33.82	37.9	41.98	42.56	47.51	52.46
0.7	33.58	37.9	42.22	42.24	47.51	52.78
0.8	33.35	37.9	42.45	41.94	47.51	53.08
0.9	33.13	37.9	42.67	41.66	47.51	53.36
1.0	32.92	37.9	42.88	41.39	47.51	53.63

ACQUISITION COSTS FOR SBI ARCHITECTURE

System	CV	R&D C50	R&D EX	R&D VARX
BSTS	0.1231	5.40	5.400	0.442
SSTS	0.1821	3.80	3.800	0.479
SBI	0.2786	4.10	4.100	1.305
CCSOIF	0.2786	3.53	3.530	0.967
SEI	0.1231	2.91	2.910	0.128
LCH	0.1231	3.40	3.400	0.175
TOTALS		23.14	23.140 MUR&D	1.870 SIGR&D

ACQUISITION COSTS FOR SBI ARCHITECTURE

System	INV C50	INV EX	INV VARX
BSTS	2.60	2.600	0.102
SSTS	5.40	5.400	0.967
SBI	25.96	25.960	52.308
CCSOIF	1.99	1.990	0.307
SEI	1.59	1.590	0.038
LCH	9.59	9.590	1.394
TOTALS	47.13	47.130 MUINV	7.424 SIGINV

ACQUISITION COSTS FOR SBI ARCHITECTURE

System	TOTALS EX	TOTALS VARX
BSTS	8.000	0.757
SSTS	9.200	2.126
SBI	30.060	61.875
CCSOIF	5.520	1.820
SEI	4.500	0.237
LCH	12.990	2.063
TOTALS	70.270	8.299
	MU	SIG
	MU	70.2700
	SIG	11.1851

Correlation between Phases 0.50

PROB	COSTRD	COSTINV	COSTTOT
0.1	20.75	37.63	55.95
0.2	21.57	40.90	60.88
0.3	22.16	43.26	64.44
0.4	22.67	45.26	67.46
0.5	23.14	47.13	70.27
0.6	23.61	49.00	73.08
0.7	24.12	51.00	76.10
0.8	24.71	53.36	79.66
0.9	25.53	56.63	84.59

PROGRAM COSTS FOR SBI ARCHITECTURE

System	CV	C50 (R&D)	EX (R&D)	VARX (R&D)
BSTS	0.1231	5.40	5.400	0.442
SSTS	0.1821	3.80	3.800	0.479
SBI	0.2786	4.10	4.100	1.305
GSTS	0.1821	1.30	1.300	0.056
MGBR	0.1231	1.30	1.300	0.026
ERIS	0.1231	2.40	2.400	0.087
TGBR	0.1231	1.10	1.100	0.018
HEDI	0.1231	1.50	1.500	0.034
CCSOIF	0.2786	4.25	4.250	1.402
SEI	0.1231	4.11	4.110	0.256
LCH	0.1231	3.40	3.400	0.175
TOTALS		32.66	32.660	2.069
			MUR&D	SIGR&D

PROGRAM COSTS FOR SBI ARCHITECTURE

System	C50 (INV)	EX (INV)	VARX (INV)
BSTS	2.60	2.600	0.102
SSTS	5.40	5.400	0.967
SBI	25.96	25.960	52.308
GSTS	0.00	0.000	0.000
MGBR	0.00	0.000	0.000
ERIS	0.00	0.000	0.000
TGBR	0.00	0.000	0.000
HEDI	0.00	0.000	0.000
CCSOIF	1.99	1.990	0.307
SEI	1.59	1.590	0.038
LCH	9.59	9.590	1.394
TOTALS	47.13	47.130	7.424
		MUINV	SIGINV

PROGRAM COSTS FOR SBI ARCHITECTURE

System	TOTALS EX	TOTALS VARX
BSTS	8.000	0.757
SSTS	9.200	2.126
SBI	30.060	61.875
GSTS	1.300	0.056
MGBR	1.300	0.026
ERIS	2.400	0.087
TGBR	1.100	0.018
HEDI	1.500	0.034
CCSOIF	6.240	2.366
SEI	5.700	0.393
LCH	12.990	2.063
TOTALS	79.790	8.355
	MU	SIG
	MU	79.7900
	SIG	12.0225

PROB	COSTRD	COSTINV	COSTTOT
0.1	30.01	37.63	64.40
0.2	30.92	40.90	69.70
0.3	31.58	43.26	73.52
0.4	32.14	45.26	76.77
0.5	32.66	47.13	79.79
0.6	33.18	49.00	82.81
0.7	33.74	51.00	86.06
0.8	34.40	53.36	89.88
0.9	35.31	56.63	95.18

Correlation Between Phases 0.50

Correlation Between Programs	---- Acquisition Costs	-----------		Program Costs	-----	
	20%	50%	80%	20%	50%	80%
0.0	63.31	70.27	77.23	72.78	79.79	86.80
0.1	62.76	70.27	77.78	72.07	79.79	87.51
0.2	62.25	70.27	78.29	71.41	79.79	88.17
0.3	61.77	70.27	78.77	70.81	79.79	88.77
0.4	61.32	70.27	79.22	70.24	79.79	89.34
0.5	60.88	70.27	79.66	69.70	79.79	89.88
0.6	60.47	70.27	80.07	69.19	79.79	90.39
0.7	60.08	70.27	80.46	68.71	79.79	90.87
0.8	59.69	70.27	80.85	68.24	79.79	91.34
0.9	59.33	70.27	81.21	67.80	79.79	91.78
1.0	58.97	70.27	81.57	67.36	79.79	92.22